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This report contains summaries of research projects in the Department of Oceanography. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstracts.

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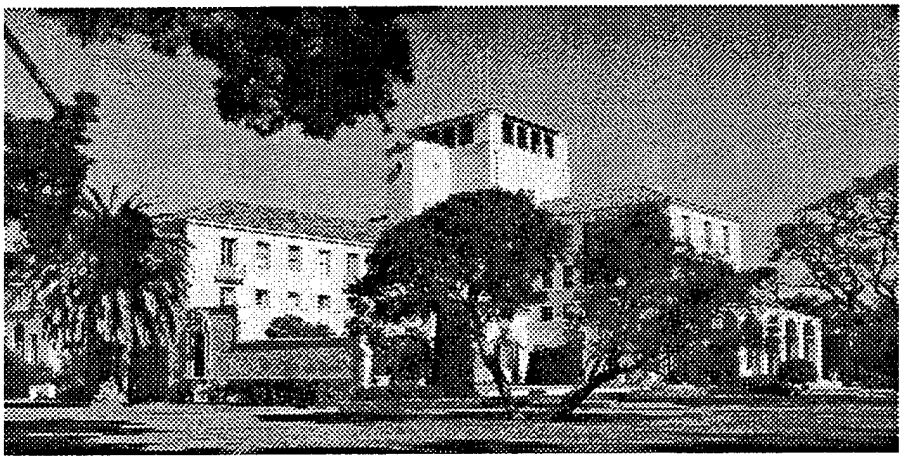
DEPARTMENT OF OCEANOGRAPHY

Roland W. Garwood, Jr.
Chair

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of U.S. and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.



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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the School's eleven academic departments, seven interdisciplinary groups, and the School of Aviation Safety. This volume contains research summaries for the projects undertaken by faculty in the Department of Oceanography during 1998. Also included is an overview of the department, faculty listing, a compilation of publications/presentations, and abstracts from theses directed by the department faculty.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the NPS Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil~code09/.

INTRODUCTION

The research program at the Naval Postgraduate School exits to support the graduate education of our students. It does so by providing militarily relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, permitting them to maintain the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. This capability is especially important at the present time when technology in general, and information operations in particular, are changing rapidly. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focussed graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at NPS consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with other government laboratories and universities, provides off-campus courses either on-site at the recipient command or by VTC, and provides short courses for technology updates.

- NPS Institutionally Funded Research Program (NIFR): The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursable sponsored, (4) to contribute to the recapitalization of major scientific equipment, and (5) to cost-share the support of a strong post-doctoral program.

- Institute for Joint Warfare Analysis (IJWA) Program: The IJWA Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of research faculty.

In 1998, the overall level of research effort at NPS was 145 faculty workyears and exceeded $35 million. The Department of Oceanography's effort was 16.19 faculty workyears and exceeded $3.1 million. The sponsored research program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY98, over 81% percent of the NPS research program was externally supported. In the Department of Oceanography 95% was externally supported.

The department's research sponsorship in FY98 is provided in Figure 1.

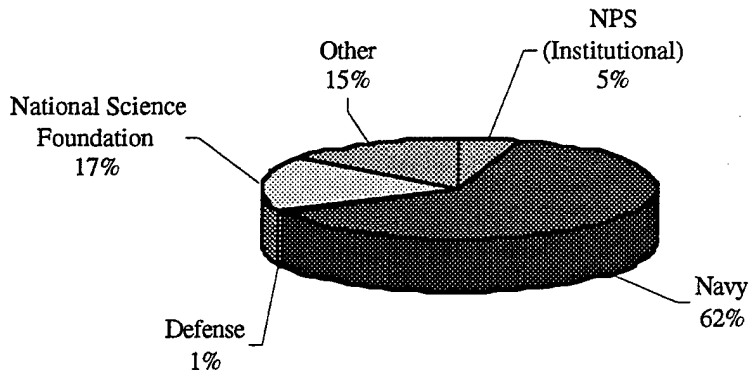

Figure 1. FY98 Sponsor Profile of the Department of Oceanography

These are both challenging and exciting times at NPS and the research program exists to help ensure that we remain unique in our ability to provide graduate education for the warfighter.

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October 1999

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DEPARTMENT SUMMARY

The Oceanography Department has developed a broad research program focused on physical oceanography to meet the anticipated future needs of the Navy. Our priority basic research themes are the development of scientific capabilities to measure, analyze, and forecast fields of littoral ocean variables which occur in association with synoptic/mesoscale processes over limited regional and temporal domains. The areas of emphasis include coastal and nearshore ocean dynamics, air-sea interaction phenomena, and boundary currents. Regions of interest include the marginal sea ice zone, coastal ocean regions, and strategic straits of the world.

Our priority applied research themes are the application of analyses and forecasts of upper ocean synoptic/mesoscale variability to Naval operations. Areas of emphasis include the impact of littoral processes, eddies and boundary currents on ocean surveillance systems, the effect of coastal ocean response storms on acoustic propagations and ambient noise and the impact that the wave climate exert on nearshore processes and beach character as pertains to mine/mine countermeasure, amphibious warfare, and special forces operations.

These research themes require the development of numerical ocean prediction and synoptic oceanography capabilities. They are achieved through employment of modem dynamical and mathematical principles, numerical and statistical methods, computational and graphical facilities, and in-situ and remote sensing observation.

The diverse talents of the department faculty apply these various techniques to solve problems of common interest. Our students are actively involved in these research programs and participate in research cruises, conference presentations, and as co-authors of research reports and papers. Much of our research results, both theoretical and applied, are incorporated into the curricula we support. A summary of focus research areas follows.

COASTAL AND NEARSHORE OCEANOGRAPHY

Under sponsorship of the Office of Naval Research, Professor M.L. Batteen is using an eddy-resolving, primitive equation coastal model to study the generation, stability, and maintenance of currents and eddies in the California and Iberian Current Systems.

Professor C.A. Collins working with Professors N. Garfield and R. Paquette, continued subsurface Lagrangian measurements of flow in the California Current system. RAFOS floats were launched between Point Arguello and Cape San Martin along the upper slope to determine regions of formation of submesoscale vortices. This work was sponsored by the Office of Naval Research.

Professor C.A. Collins, with support from the National Science Foundation and the Monterey Bay National Marine Sanctuary, conducted a series of hydrographic cruises off Central California. The cruises occupied CalCOFI Line 67 to a distance of 200n. miles from shore and were designed to determine the response of local waters to El Nino conditions. Professors L. Rosenfeld and C.A. Collins also helped in the collection of current meter and sediment trap data during this time period; these observations were supported by Monterey Bay Aquarium Research Institute and were acquired at two moorings located along CALCOFI Line 67.

Professors C.A. Collins and S. Ramp, with Dr. Marlene Noble of USGS, observed currents at three moorings located near the Deep Ocean dumpsite off San Francisco. This project was sponsored by the Environmental Protection Agency.

Professor C.A. Collins continued work with the Naval Oceanographic Office to develop tactical decision aids for use in mine warfare which are based upon the characteristics of ocean currents.

Associate Professor P.C. Chu, under the sponsorship of the Office of Naval Research, has continued working on coastal ocean analysis and prediction. The major studies include: (a) two kinds of predictability in Lorenz system and ocean climate systems, (b) investigation of error propagation from winds to ocean models, (c) verification of Haney-type surface thermal boundary conditions, (d) development of a coastal atmosphere-ocean coupled system (CAOCS), (e) development of a geometric model for observational T, S data analysis, (f) identification of the South China Sea warm-core/cool-core eddies using the Navy's MOODS data, AXBT data, and the National Meteorological Center (NCEP) sea surface temperature (SST) fields (1982-94), (g) development of high-order difference schemes, (h) development and verification of P-vector inverse method, and (i) investigation of interdecadal oscillations in wind and thermally driven ocean general circulation model (OGCM).

Associate Professor P.C. Chu, under the sponsorship of the Naval Oceanographic Office, continued (1) to investigate environmental effects on the joint warfare simulations at various scales (e.g., theater level, technical level, ...) and to incorporate the Navy's Meteorological and Oceanographic (METOC) data and models effectively into the joint warfare

simulation models, such as RESA and mine warfare models obtained from COMMINWARCOM; (2) to estimate the value added of knowing the METOC data; and (3) to quantitative analyze the value added of knowing the environment and to identify the measure of effectiveness of METOC knowledge.

Associate Professor. P.C. Chu, under the sponsorship of NPS, has investigated the sensitivity of the Joint Simulation Systems to the environment. At the same time, he is incorporating realistic environments into high-resolution, high fidelity wargames of mine warfare.

Professor T.H.C. Herbers is investigating the dynamics of ocean surface waves in shallow coastal waters using theory and field observations. Current research projects (funded by the Office of Naval Research) focus on nonlinear wave-wave interactions, shoaling of waves on beaches, the generation of surf beat, and the propagation of waves over a continental shelf.

Professor L. Le in cooperation with Dr. P. Luong (NAVOCEANO), under multi-year sponsorship of the ONR Navy Ocean Modeling and Prediction Program (NOMP), developed a Coastal Ocean System (COS) with curvilinear nearly-orthogonal, multi-block grids, which better handle complicated coastlines, bathymetry and open boundary conditions. The generated numerical grids were coupled to the coastal ocean models with data assimilation schemes. Under the sponsorship of ONR NOMP, Professors L. Le, J. Paduan, and Dr. P. Luong (NAVOCEANO) use the Monterey Bay COS to study the response of MOB to diurnal wind and tidal forcing.

Professor J. D. Paduan, with funding from ONR and NSF, is undertaking studies of coastal circulation problems in Monterey Bay, CA and off Chesapeake Bay, VA using High Frequency (HF) radar-derived currents. Of particular interest are the coastal phenomena of sea-breeze driven currents related to sea-land temperature differences and internal tidal currents generated when sea level fluctuations interact with the sloping ocean bottom. A primitive-equation modeling study is also underway using the Princeton Ocean Model to simulate the three-dimensional generation and propagation of internal tides around the Monterey Submarine Canyon.

Professor P.-M. Poulain has continued to make direct measurements of the surface currents and the surface temperature in the Adriatic Sea using satellite-tracked drifters in order to describe the variability of the surface mesoscale structures and gain knowledge on their dynamics. This project, in close collaboration with NATO/SACLANTCEN and Italian research institutes, is sponsored by the Office of Naval Research.

Professor P.-M. Poulain, under the sponsorship of the Office of Naval Research, has studied the transport properties in the Adriatic basin using surface drifter data collected in 1994-96 and using a Lagrangian transport model.

Professor L. Rosenfeld is studying internal waves, particularly at tidal frequencies, in the littoral zone. She is working with Professor Paduan on model studies funded by ONR, and is making field measurements, funded by NSF with colleagues from the University of Washington.

Under sponsorship from the National Ocean Partnership Program, Professors J.D. Paduan, S.R. Ramp, C.S. Chiu, C.A. Collins, L.K. Rosenfeld, and N. Garfield began a combined observation, modeling and data assimilation program based on the network of moorings, HF radar instruments, and acoustic tomography sections around Monterey Bay. The Innovative Coastal-Ocean Observing Network, or ICON, involves science and engineering partners from seven different institutions in addition to NPS, which acts as the central point for the program.

Professor Steven R. Ramp, with funding from the Office of Naval Research and the National Ocean Partnership Program, is studying the dynamics of the continental shelf and slope along the U.S. West Coast and the circulation of the Asian marginal seas. He is presently doing a retrospective data analysis of the South China Sea and participating in the moored buoy element of the Innovative Coastal-ocean Observing Network in and around the Monterey Bay.

Professors T.P. Stanton, E.B. Thornton, and T.H.C. Herbers are participating in the Shoaling Waves DRI sponsored by ONR that will develop an improved model of surface gravity wave propagation across continental shelves. This work includes unique observations of dissipation in the wave forced bottom boundary layer, and an extensive field program at Duck, NC, in September 1999.

Professors E.B. Thornton and T.P. Stanton are developing models to predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the nearshore zone, and comparing the models to comprehensive field data they have acquired. This work is sponsored by ONR. Under a separate ONR contract, they are testing and evaluating a 3D morphodyamic model to be transitioned to the fleet.

DEPARTMENT SUMMARY

ACOUSTICAL OCEANOGRAPHY

Professors R.H. Bourke and J.H. Wilson are analyzing transmission loss and bottom backscattering data from shallow water areas with a goal of developing a bottom reverberation algorithm for the AN/SQS-53C sonar when operating in shallow coastal waters. They have recently expanded this research to include the new helicopter sonar (ALFS) and the low frequency active (LFA) sonar. Investigations in the past year have centered on quantifying the energy spreading loss phenomenon. The sponsor is NUWC.

Professors R.H. Bourke and J.H. Wilson are developing a predictive ambient noise model for submarines operating in the Arctic Ocean which will forecast periods of extremely loud (>95th percentile level) and quiet (<5th percentile) noise levels. The ice prediction model, PIPS is being modified to produce output fields of energy disruption as an indicator of pressure ridge formation. We are also studying RADARSAT imagery to verify the response of the ice deformation field to windforcing. Sponsor is ONR.

Professor C.-S. Chiu is analyzing experimental data collected from the Shelfbreak PRIMER field study, which took place in a shelf-slope region south of New England, to (1) determine the effects of seasonal and mesoscale variability of the shelf-break frontal thermal structure on the transmission of sound from the slope to the shelf, (2) relate the temporal and spatial variability of the acoustic propagation with the ocean variability in the frontal zone, and (3) obtain tomographic maps of the frontal region for use in the characterization of the ocean variability. The research is funded by ONR.

Professors C.-S. Chiu and C. A. Collins are converting the former Pt. Sur SOSUS facility into a dual-use Ocean Acoustic Observatory for the purpose of marine research, and investigating the feasibility of tracking and counting blue whales in Central California water using this former SOSUS hydrophone array. The research is funded by SERDP/ONR.

Professor C.-S. Chiu is organizing international workshops in shallow-water acoustics to plan a collaborative international experiment in the seas of China. Such an experiment will focus on studying the physics and variability of sound propagation and scattering that are unique to the coastal waters of the Asian Pacific region. The research is funded by ONR.

Professors C.-S. Chiu and C.A. Collins are studying the California Current System using the NPS Ocean Acoustic Observatory and tomographic inverse techniques. This is part of an inter-institutional partnership project called, "Ocean Acoustic Observatory Federation." The research is funded by NOPP.

AIR-SEA INTERACTION AND OCEAN TURBULENCE

Professor R.W. Garwood has a five-year grant from the National Science Foundation to study polar sea convective instabilities. The major scientific objective of this study is to understand the coupled ocean mixed layer-ice system response to the passage of atmospheric storms. The most intense surface cooling and wind stresses in the Arctic are associated with storms, and their long-term cumulative effects on the heat and water budgets for the Arctic Ocean are predicted by including (i) realistic mixed layer physics, (ii) ice thermodynamics, and (iii) three-dimensional wind-driven ocean circulation.

Ms. Arlene Guest and Professor Garwood are in the final year of a four-year project, "Equatorial Mixed Layer System," with grant money from the National Oceanic and Atmospheric Administration and the National Science Foundation. This project is part of the TOGA Coupled Ocean Atmosphere Response Experiment (COARE), to explain large-scale feedback between the ocean and atmosphere in the Western Pacific.

Professor R.W. Garwood is sponsored by the Office of Naval Research to simulate the response of Lagrangian drifters to convection in the Labrador Sea. Understanding the drifter response will lead to optimal strategies for deployment of drifting instruments and help in the interpretation of observations obtained by instruments under the influence of oceanic convection. A key scientific objective is to understand the turbulent kinetic energy budget for free and forced deep oceanic convection, and the processes leading to deep penetrative convection in subpolar seas. The method is to use nonhydrostatic oceanic large-eddy simulation (LES) to predict the unsteady three-dimensional turbulent velocity, temperature, salinity, and pressure fields on a model grid. Typical grid domains are 1-4 km deep by 3-12 km horizontally, resolving the OPBL turbulence from the integral scale (dominant turbulent eddy size) into the inertial range. These fields are archived or used directly to advect Lagrangian drifter models (LDM's). LDM's are designed to simulate a variety of drifter designs: pure Lagrangian, isobaric, glider, or propelled (AUV's). A major milestone passed during FY98 was the large-eddy simulation of Labrador Sea convection during the 28-day ship-observed focus period of the 1997 field experiment.

Professor L. Le developed an air-wave-sea interaction model of semi-empirical turbulence and similarity theories. The model was used in the modeling of vertical distributions of turbulent dissipation in the Upper Oceanic Turbulent Layer under surface breaking wave conditions. This work was under multi-year sponsorship of ONR.

Professors W. Maslowski and R.W. Garwood have been awarded a new three-year grant from the National Science Foundation to model shelf-basin circulation and mixing in the Chuchi Sea. This grant was awarded as part of Phase I of a new Arctic Shelf-Basin Initiative.

NUMERICAL PREDICTION AND DATA ASSIMILATION

Professors J.L. McClean and A.J. Semtner, sponsored by the National Science Foundation, continue to collaborate with World Ocean Circulation Experiment (WOCE) investigators to evaluate the global 1/6-degree Parallel Ocean Program (POP) model and use a combination of POP output and WOCE data to understand ocean processes in particular basins/ regions. Efforts have concentrated on the South Atlantic, the Indonesian Through Flow, and the Pacific Ocean. In addition, output from a 1/3-degree fully global version of POP (Arctic included), forced with reanalyzed 1979-1993 European Center for Medium-range Weather Forecasts products, is also used towards this end.

Professors R. Tokmakian and A. Semtner continue to produce, analyze, and distribute output from global 1/4-degree 20-level ocean models forced by reanalyzed 1979-94 atmospheric data of the European Center for Medium-range Weather Forecasts. Recent integrations using ECMWF operational datasets have allowed the simulations to include the recent El Nino of 1997-98. This multi-year research is supported by the National Science Foundation and cost-shared by NPS. Also, a NASA grant which includes Professor J. McClean is analyzing model output to find satellite observable indicators of interannual to decadal changes in ocean circulation.

Professors A.J. Semtner, W. Maslowski, and Y. Zhang began in late FY 1998 to develop a new Polar Ice Prediction System (PIPS 3.0) under sponsorship of the Office of Naval Research. This research uses a highly parallel Arctic ice-ocean model as the foundation for improved dynamics and thermodynamics. The model will be transitioned to operational status in collaboration with scientists from Stennis Space Center.

Professors A. Semtner, R. Tokinakian, J. McClean, W. Maslowski, and Y. Zhang began a five-year project sponsored by the Department of Energy on the Application of Parallel Ocean and Climate Models to Decade/Century Prediction. The research involves many simulations of ocean-ice circulation and of ocean-atmosphere-ice interactions on long time scales, using very large supercomputers at the National Center for Atmospheric Research, Los Alamos National Laboratory, the National Energy Research Supercomputing Center, and the Arctic Region Super-computing Center. The most ambitious simulations are conducted in collaboration with investigators at the first two sites. Ocean grid sizes range from 1/3 degree to as fine as 1/10 degree, with 20-40 vertical levels. Extensive comparisons with data and detailed analyses are in progress.

MARINE OPERATIONS

Mr. P. Jessen and Professor R.W. Garwood managed shipboard support for NPS at-sea instruction and research projects off the Central California coast. Twenty-four days of operations were carried out on the RV *Pt. Sur*. Students and faculty participated in these shipboard projects from both the Departments of Oceanography and Meteorology. The sponsor for this project is the Commander, Naval Oceanography Command. NPS acquired the Point Sur SOSUS array and it is being used in a variety of reimbursable-funded research projects.

Professor J.R. Clynch conducted an effort to improve the at-sea (non-differential) OPS horizontal position from 10 m to about 1 m. The third of three at-sea experiments was conducted in 1998 in support of this goal on the RV *Pt. Sur*. This experiment contains all the elements of a possible system, multiple GPS receivers, atomic oscillator, and inertial attitude systems. For the National Imagery and Mapping Agency (NIMA), Dr. Clynch is studying the means to improve road locations in a tactical situation using commonly available OPS receivers. This study is being done with Professors Franke and Neta of the Mathematics Department. Work on Antarctic aircraft landings systems is ongoing. A system was deployed to McMurdo to monitor the environmental effects on the Mobile Microwave Landing System (MMLS) being tested in the 1998/99 operational season. The effects on the ice sheet of the landing of fully loaded CS aircraft was also measured.

PROCESS MODELING STUDIES OF THE CALIFORNIA CURRENT SYSTEM

Mary L. Batteen, Associate Professor
Department of Oceanography
Sponsors: National Science Foundation and Naval Postgraduate School

OBJECTIVE: The overall objectives of this research are to investigate the generation, stability, and maintenance of currents and eddies in the California Current System (CCS) and other eastern boundary current systems such as the Leeuwin and Canary Current Systems, and to better describe their contributing forcing mechanisms and their relative importance.

SUMMARY: Process-oriented modeling studies have been used to explore the roles of wind forcing thermohaline gradients, and coastal irregularities in the generation of currents and eddies in the CCS and other eastern boundary current systems such as the Leeuwin and Canary Current Systems.

PUBLICATIONS:

Batteen, M.L. and Vance, P.W., "Modeling Studies of the Effects of Wind Forcing and Thermohaline Gradients on the California Current System," *Deep-Sea Research II*, Vol. 45, pp. 1507-1556, 1998.

Batteen, M.L. and Huang, M.J., "Effect of Salinity on Density in the Leeuwin Current System," *Journal of Geophysical Research*, Vol. 103, No. C11, pp. 24,693-24,721, 15 October 1998.

Batteen, M.L. and Butler, C.L., "Modeling Studies of the Leeuwin Current Off Western and Southern Australia," *Journal of Physical Oceanography*, Vol. 28, pp. 2199-2221, November 1998.

Batteen, M.L. and Vance, P.-W., "Modeling Studies of the Effects of Wind Forcing and Thermohaline Gradients on the California Current System," *Research Activities in Atmospheric and Oceanic Modeling, CAS/JSC Working Group on Numerical Experimentation*, Vol. 27, 8.1, January 1998.

Bryan, D.W., Batteen, M.L., and Buch, E.J., "A Wind-Forced Modeling Study of the Canary Current System from 30 N to 42.5 N," Naval Postgraduate School Technical Report, NPS-OC-98-003, June 1998.

Cipriano, N.J., Batteen, M.L., and Monroe, J.T., "Analysis of Eddy-Resolving Model of the California Current System," Naval Postgraduate School Technical Report, NPS-OC-98-004, September 1998.

CONFERENCE PRESENTATIONS:

Batteen, M.L., "Modeling Studies of Wind and Thermohaline Forcing in the California Current System," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, 9 February 1998.

Batteen, M.L., "Modeling Studies of Wind- and Thermally-Driven Eastern and Southern Boundary Coastal Regions," South East Indian Ocean and Great Australian Bight USA/Australia Bilateral Workshop, Port Lincoln, Australia, 29 September 1998.

THESES DIRECTED:

Bryan, D.W., "A Wind-Forced Modeling Study of the Canary Current System from 30 N to 42.5 N," Master's Thesis, Naval Postgraduate School, June 1998.

Cipriano, N.J., "Analysis of Eddy-Resolving Model of the California Current System," Master's Thesis, Naval Postgraduate School, September 1998.

Cox, A.W., "Modeling Studies of the Effects of Seasonal Wind Forcing and Thermohaline Gradients on the Leeuwin Current System," Master's Thesis, Naval Postgraduate School, December 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Coastal Oceanography, Ocean Modeling, Eastern Boundary Currents

DEVELOPMENT OF AN ARCTIC LOW-FREQUENCY AMBIENT NOISE MODEL

Robert H. Bourke, Professor
James H. Wilson, Research Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: This is a multiyear project whose goal is to develop a low frequency Arctic ambient noise model capable of predicting periods of extremely high and low noise conditions. The predictions are designed to assist and optimize submarine operations while they are maneuvering under the Arctic ice pack.

SUMMARY: We have previously demonstrated the capability of an empirically-based ambient noise model, driven by surface winds, to closely estimate the noise field data recorded by ice-mounted drifting buoys. Equations have been developed to modify the Navy's operational Polar Ice Prediction System (PIPS) to produce output fields of energy dissipation rate. Such fields can serve as a direct measure of ridging activity. The student, LT Speckhahn, just recently completed an analysis which demonstrated the high potential for using RADARSAT RGPS imagery to quantify the spatial and temporal degree of lead formation and pressure ridging activity in response to storm forcing. A three-month ambient noise time series measured at the SHEBA site has been acquired (Nov 1997-Feb 1998) and the RGPS data for this time period. These will be used as inputs to create a dynamic noise prediction model.

THESIS DIRECTED:

Speckhahn, M.M., "Identification of Acoustically Active Arctic Pressure Ridges Through the Use of RADARSAT Geophysical Processor System (RGPS) Sea Ice Products," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Sea Ice, Ambient Noise, Arctic Ocean, RADARSAT

ONR CHAIR IN ARCTIC MARINE SCIENCE

Robert H. Bourke, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The Chief of Naval Research has established at the Naval Postgraduate School a Chair in Arctic Marine Science. The objectives of the Chair are to foster oceanographic research in the Arctic, acquaint Naval officer students with Arctic problems, reduce results of pure research to operational usage, and publicize Navy interest in the Arctic.

SUMMARY: Professor Bourke served as administrator of the Chair, handling such details as selecting Chair candidates, writing IPAs and proposals, and setting up visits and seminars for the Chair incumbent.

Professor William D. Hibler, III, from Dartmouth College, was the Chairholder during FY98. While at NPS Dr. Hibler wrote a code to modify PIPS 2.0 to produce output fields of energy dissipation rate, a necessary component for an Arctic ambient noise model being developed by Professors Bourke and Wilson. He also assisted Professor Yuxia Zhang in developing an energy-conserving ice rheology for her new high resolution coupled Arctic ice model. He also led the session on ice mechanics at the PIPS 3.0 workshop held at NPS.

A search was conducted for the follow-on Chairholder. Professor Martin O. Jeffries from the University of Alaska has been selected. He will be in residence from October 1998 to September 1999 and will conduct work on sea ice characteristics in both Arctic and Antarctic environments.

PUBLICATIONS:

Bourke, R.H. and Curtin, T.B., (eds.), "Arctic Studies," *Naval Research Reviews*, 1 (l), 1998.

Hibler, W.D., III, "A Curvilinear Coordinate Energy Conserving Sea-Ice Dynamics Model for PIPS," Naval Postgraduate School Technical Report, NPS-OC-98-006, January 1999.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Arctic Ocean, Antarctic Region, Sea Ice

MODEL/DATA COMPARISONS OF REVERBERATION AND ENERGY SPREADING LOSS FOR THE AN/SQS-53C AND ALFS SONARS USING LONG BAY LITTORAL WARFARE ADVANCE DEVELOPMENT (LWAD) DATA

Robert H. Bourke, Professor
James H. Wilson, Research Professor
Department of Oceanography
Sponsor: Naval Undersea Warfare Center

OBJECTIVE: This is a continuation of a multi-year program to improve the operational performance of tactical active sonars operating in shallow water with particular emphasis on bottom interaction for both propagation loss and reverberation. The objective is to assess the LWAD database for Long Bay and design a data demultiplexing plan, including software, to produce MATLAB files of LWAD time series data.

SUMMARY: LWAD data for Long Bay, emphasizing up/down/cross-slope propagation, for the AN/SQS-53C and ALFS sonars have been located with the assistance of our colleagues at NUWC. Software is being designed to demultiplex the data so that the output data are compatible for analysis using MATLAB.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: LWAD, Tactical Active Sonars, Long Bay

SHELFBREAK PRIMER DATA ANALYSIS: ACOUSTIC PROPAGATION AND OCEAN TOMOGRAPHY

Ching-Sang Chiu, Professor
Department of Oceanography and Undersea Warfare Academic Group
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVES: The acoustic objectives of the Shelfbreak PRIMER field study, which took place in a shelf-slope region south of New England, are: (1) To determine the effects of seasonal and mesoscale variability of the shelf-break frontal thermal structure on the transmission of sound from the slope to the shelf. (2) To relate the temporal and spatial variability

of the acoustic propagation with the ocean variability in the frontal zone. (3) To obtain tomographic maps of the frontal region for use in the characterization of the ocean variability.

SUMMARY: Based on cross-shelf summer temperature sections obtained by a SeaSoar, the variability of the modal arrival structure caused by a mesoscale event was computed using a broadband, coupled normal-mode propagation model. This event corresponded to the intrusion of and later exit of a warm, saline small eddy, the remnant of a warm-core ring absorbed earlier by the Gulf Stream. This intrusion caused significant distortion in the frontal boundary. The modeled arrival structure for the different days shows that the resultant travel-time changes are on the order of 100 ms, which is in agreement with the observed changes discussed above. The model results also show an increase of signal level during the warm intrusion. This model prediction of a warm enhancement is also consistent with the VLA observations.

Using daily cross-front winter sound-speed sections provided by the Harvard group, an initial modeling study of the variability of the winter acoustic transmissions was also conducted. These winter sound-speed fields were the output of a Harvard ocean model run with assimilated winter oceanographic data. Unique to the winter sound-speed fields is the presence of complex double ducts (i.e., an upward refracting surface duct and a downward refracting bottom duct) on the slope. The double ducts merged into a single upward-refracting channel on the shelf. Large temporal variability is found in the modeled TL and modal coefficients. The depth of the boundary separating the surface and bottom ducts on the slope as well as its range variations are found to control, to a large extent, the initial partitioning of the acoustic energy (i.e., how much energy goes into and becomes trapped in the surface duct and how much remains in the bottom duct). The range variations of this boundary also causes significant mode coupling on the slope. Therefore, the temporal variability of this boundary is likely to be responsible for the large fluctuations in the slope-to-shelf winter sound field.

An inverse tomographic analysis was performed for studying the frontal variability. In deriving the tomographic maps, an adaptive beamformer was first used to detect, resolve and track individual acoustic ray and modal arrivals from a 224-Hz and a 400-Hz source on the slope to a vertical array on the shelf. A modal inverse technique was then applied to the resolved arrivals to produce a time series of cross-frontal images of ocean temperature. The tomographic observations were interpreted together with the SeaSoar, acoustic doppler current profiler (ADCP), and thermistor data.

PUBLICATIONS:

Chiu, C.-S., "Realistic Simulation Studies of Acoustic Signal Coherence in the Presence of an Internal Soliton Wavepacket," *Proceedings of the IOS/WHOI/ONR Internal Solitary Wave Workshop,* Victoria, Canada, 27-29 October 1998.

Headrick, R.H., Lynch, J.F., Apel, J., Badiey, M., Chiu, C.-S., Finnette, S., Orr, M., Pasewark. B., Turgut, A., Wolf, S., Kemp, J., Newhall, A., von der Heydt, K., and Tielbuerger, D. (SWARM Group), "Acoustic Normal Mode Fluctuation Statistics in the 1995 SWARM Internal Wave Scattering Experiment," *Journal of the Acoustical Society of America,* submitted and revised, 1998.

CONFERENCE PRESENTATIONS:

Chiu, C.-S., "Realistic Simulation Studies of Acoustic Signal Coherence in the Presence of an Internal Soliton Wavepacket," IOS/WHOI/ONR Internal Solitary Wave Workshop, Victoria, Canada, 27-29 October 1998.

Chiu C.-S., Lynch, J.F., Gawarkiewica, G., Miller, C.W., and Sperry, B., "Tomographic Maps of the New England Shelfbreak Front," American Geophysical Union Ocean Science Meeting, San Diego, CA, February 1998.

THESIS DIRECTED:

Miller, C.W., "Estimating the Acoustic Modal Arrivals Using Signals Transmitted from Two Sound Sources to a Vertical Line Hydrophone Array in the 1996 Shelfbreak PRIMER Experiment," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Littoral, Acoustics, Nowcast, Shelfbreak Fronts

MONITORING WHALES USING THE PT SUR ACOUSTIC ARRAY - A FEASIBILITY STUDY

Ching-Sang Chiu, Professor
Curtis A. Collins, Professor
Department of Oceanography and Undersea Warfare Academic Group
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVES: (1) To investigate the feasibility of locating, tracking, counting and determining the transit paths of blue whales in central California water using the former Point Sur SOSUS hydrophone array. (2) To convert the former Point Sur SOSUS facility into a dual-use Ocean Acoustic Observatory for the purpose of marine research.

SUMMARY: Detecting, classifying, localizing, and tracking vocalizing whales using receiver arrays at long ranges is a combined signal processing, underwater acoustic, bio-acoustic, and physical oceanographic problem. First, knowledge of the loudness and frequency-time distribution of the different whale sounds is required for classification purposes. Equally important is the understanding of the basic structure and variability of the ocean sound channel. The ocean scrambles the vocalized signal by its multi-paths as the signal propagates to a distant receiver. The ability to predict the mean and variance of the propagation is thus required to unscramble the received signal and to constrain the uncertainty.

A four-day field experiment was designed and conducted to test the feasibility of detecting, classifying, localizing, and tracking blue whales at long ranges acoustically using a former SOSUS listening array located at the Naval Postgraduate School Ocean Acoustic Observatory (OAO) at Point Sur, California. The experiment was a collaborative effort involving scientific investigators and graduate students from the Naval Postgraduate School, Monterey Bay Aquarium Research Institute, University of California at Santa Cruz, and NOAA's Monterey Bay National Marine Sanctuary Office. During the experiment, full-array data were archived continuously at the OAO using a newly developed 32-channel data acquisition system sampling at 2 kHz. In concert with the shore-based acoustic monitoring, an aircraft was assigned to locate blue whales in the Monterey Bay National Marine Sanctuary and to direct a research vessel to a whale site. The research vessel was manned with observers and instrumented with a towed hydrophone array to ground-truth the locations of the blue whales and classify the vocalized near-field signals. These shipboard measurements were required to provide a means to separate the source signal characteristics from the multipath signatures for the calibration and validation of broadband, model-based localization methods. Data analysis as well as computer modeling efforts in FY98 have focused on the understanding of the characteristics of the blue whale calls, the predictability of the propagation of sound in the central California coastal ocean, the uniqueness of the location-dependent multipath structure and the robustness of various matched signal algorithms, all of these are fundamental to the applicability of the concept of locating, tracking and counting blue whales using the former SOSUS array at Point Sur.

PUBLICATION:

Chiu, C.-S., Morvillez, T., and Collins, C.A., "Monitoring Temperature Variability Along the California Coast Using Acoustic Tomography," *Proceedings of the 16th International Congress on Acoustics and the 135th ASA Meeting of the Acoustical Society of America*, pp. 387-388, June 1998.

CONFERENCE PRESENTATIONS:

Morvillez, T., Chiu, C.-S., Collins, C.A., "Monitoring Temperature Variability Along the California Coast Using Acoustic Tomography," 16th International Congress on Acoustics and 135th Meeting of the Acoustical Society of America, Seattle, WA, 20-26 June 1998.

Chiu, C.-S., "Using SOSUS to Track Whale Migration," International Advanced Studies Institute Symposium on Detection and Analysis of Subsurface Objects and Phenomena, Monterey, CA, 19-21 October, 1998.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Environmental Quality

KEYWORDS: Coastal, Acoustics, Whale Monitoring, Alternate Uses

INTERNATIONAL WORKSHOPS IN SHALLOW-WATER ACOUSTICS

Ching-Sang Chiu, Associate Professor
Department of Oceanography and Undersea Warfare Academic Group
Sponsor: Office of Naval Research

OBJECTIVES: The long-term goal is to formulate and conduct a collaborative international experiment in the seas of China. Such an experiment will focus on studying the physics and variability of sound propagation and scattering that are unique to the coastal waters of the Asian Pacific region. The FY98 objectives were: (1) To identify the outstanding research topics in shallow-water acoustics which are of common interest to all participating countries and which might form the basis for a collaborative U.S.-Asia experiment in the seas of China. (2) To assess the scientific approaches and logistic issues for such an experiment. (3) To assess the available technology to support the field effort. (4) To identify potential sites for the experimental program and investigate the environmental conditions. (5) To recommend a plan of action that will lead to a comprehensive international experiment in 2000.

SUMMARY: The approach was to hold a series of international workshops, inviting top-notch underwater acousticians and acoustical oceanographers from seven different countries including China, Japan, Korea, Singapore, Taiwan, Russia, and the USA, to jointly investigate the scientific, engineering and logistic rationales that might form the basis for a comprehensive shallow-water acoustic experiment, develop common or complimentary experimental objectives, identify international resources, and formulate a plan for the coordination and execution of the experiment.

Two International Workshops were organized. The Phase I Workshop was held in San Francisco on 8-9 December 1997. The Phase II Workshop was held in Seattle on 27 June 1998. Two technical reports were generated and distributed to the participants. The reports summarize the presentations, discussions and findings of both the Phase I and Phase II Workshops, respectively.

The Phase I Workshop featured a series of short presentations by the representatives of the different countries on their research interests, and what resources they might be able to contribute to a collaborative experiment if it were to take place in 2000. A group discussion on potential sites, research vessels, surveying and moored equipment, and scientific issues was also carried out.

The discussion of a collaborative international experiment was continued in the Phase II Workshop. The Phase II Workshop resulted in the establishment of a comprehensive list of experimental objectives and a preliminary experimental configuration. The objectives include:

1. Understand sound propagation along and across multiple fronts.
2. Investigate the scattering effects of the linear and non-linear internal waves.
3. Examine the acoustic effects of a strong fresh-water plume.
4. Investigate the forward scattering properties of bottom inhomogenieties.
5. Understand the geological and acoustical signature of stratigraphy produced by river sedimentation.
6. Investigate directional reverberation in an inhomogeneous medium (ocean and bottom).
7. Investigate properties of the coastal ambient noise field.
8. Investigate higher frequency coastal acoustics ($f > 1000$ Hz).
9. Investigate horizontal array coherence, as well as vertical and temporal coherence.
10. Can we learn to model and predict these effects?

PUBLICATIONS:

Chiu, C.-S. and Denner, W.W., "Report on the Office of Naval Research International Workshop on Shallow Water Acoustics, San Francisco, CA, 8-9 December 1997," Naval Postgraduate School Technical Report, NPS OC-98-002PR, March 1998.

Chiu, C.-S. and Denner, W.W., "Report on the Office of Naval Research International Phase II Workshop on Shallow Water Acoustics, Seattle, WA, 27 June 1998," Naval Postgraduate School Technical Report, NPS OC-98-005PR, September 1998.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Shallow-Water Acoustics

CALIFORNIA CURRENT MONITORING USING THE NPS OCEAN ACOUSTIC OBSERVATORY

Ching-Sang Chiu, Professor
Curtis A. Collins, Professor
Department of Oceanography and Undersea Warfare Academic Group
Sponsor: National Science Foundation and Office of Naval Research

OBJECTIVES: This is part of an inter-institutional partnership project called "Ocean Acoustic Observatory Federation." The Naval Postgraduate School (NPS) component has two specific objectives: (1) The operation/maintenance of the NPS Ocean Acoustic Observatory at Point Sur. (2) The implementation of a real-time ocean acoustic tomography network to monitor the California Current System.

SUMMARY: On the operation/maintenance of the Point Sur Observatory, the accomplishments to date include: (1) Developed and installed a UNIX-based multi-channel data acquisition system at Point Sur. (2) Continued continuous unclassified (single-phone) data collection and distribution to approved official users, and began continuous classified (full-array) data archival. (3) Continued trouble-shooting the full-array data acquisition system for increased reliability. (4) Certification of the secure processing facility at NPS has been completed for the NPS side of the secure T1 data link. (5) Construction work has begun for the telephone system upgrade repair. This will provide the adequate services for both analog voice lines and the T1 data line to NPS.

The implementation of the ocean-margin tomography observational network to study the California Current will involve the deployment of a Scripps' HLF-5 sound source on top of the Hoke Seamount, 600 km off shore. The signal transmissions will be monitored by (former) SOSUS receiver arrays at Point Sur, San Nicholas and Barbers Point. The planning of an April cruise to deploy the source has begun. The planning involves mooring design, hardware procurement, signal transmission scheduling, conductivity, temperature, depth (CTD) grid design, and addressing marine mammal compliant issues.

CONFERENCE PRESENTATION:

Chiu, C.-S., "The NPS Ocean Acoustic Observatory and Coastal Tomography," First Meeting of the Ocean Acoustic Observatory Federation, La Jolla, CA, 9-10 September 1998.

DoD KEY TECHNOLOGY AREA: Sensors, Battlespace Environments

KEYWORDS: SOSUS, Alternate Uses, Coastal Tomography, California Current

SHELFBREAK PRIMER DATA ANALYSIS: ACOUSTIC PROPAGATION AND OCEAN TOMOGRAPHY

Ching-Sang Chiu, Professor
Department of Oceanography and Undersea Warfare Academic Group
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVES: The acoustic objectives of the Shelfbreak PRIMER field study, which took place in a shelf-slope region south of New England, are: (1) To determine the effects of seasonal and mesoscale variability of the shelf-break frontal

thermal structure on the transmission of sound from the slope to the shelf. (2) To relate the temporal and spatial variability of the acoustic propagation with the ocean variability in the frontal zone. (3) To obtain tomographic maps of the frontal region for use in the characterization of the ocean variability.

SUMMARY: Based on cross-shelf summer temperature sections obtained by a SeaSoar, the variability of the modal arrival structure caused by a mesoscale event was computed using a broadband, coupled normal-mode propagation model. This event corresponded to the intrusion of and later exit of a warm, saline small eddy, the remnant of a warm-core ring absorbed earlier by the Gulf Stream. This intrusion caused significant distortion in the frontal boundary. The modeled arrival structure for the different days shows that the resultant travel-time changes are on the order of 100 ms, which is in agreement with the observed changes discussed above. The model results also show an increase of signal level during the warm intrusion. This model prediction of a warm enhancement is also consistent with the VLA observations.

Using daily cross-front winter sound-speed sections provided by the Harvard group, an initial modeling study of the variability of the winter acoustic transmissions was also conducted. These winter sound-speed fields were the output of a Harvard ocean model run with assimilated winter oceanographic data. Unique to the winter sound-speed fields is the presence of complex double ducts (i.e., an upward refracting surface duct and a downward refracting bottom duct) on the slope. The double ducts merged into a single upward-refracting channel on the shelf. Large temporal variability is found in the modeled TL and modal coefficients. The depth of the boundary separating the surface and bottom ducts on the slope as well as its range variations are found to control, to a large extent, the initial partitioning of the acoustic energy (i.e., how much energy goes into and becomes trapped in the surface duct and how much remains in the bottom duct). The range variations of this boundary also causes significant mode coupling on the slope. Therefore, the temporal variability of this boundary is likely to be responsible for the large fluctuations in the slope-to-shelf winter sound field.

An inverse tomographic analysis was performed for studying the frontal variability. In deriving the tomographic maps, an adaptive beamformer was first used to detect, resolve and track individual acoustic ray and modal arrivals from a 224-Hz and a 400-Hz source on the slope to a vertical array on the shelf. A modal inverse technique was then applied to the resolved arrivals to produce a time series of cross-frontal images of ocean temperature. The tomographic observations were interpreted together with the SeaSoar, ADCP and thermistor data.

PUBLICATIONS:

Chiu, C.-S., "Realistic Simulation Studies of Acoustic Signal Coherence in the Presence of an Internal Soliton Wavepacket," *Proceedings of the IOS/WHOI/ONR Internal Solitary Wave Workshop*, Victoria, Canada, 27-29 October 1998.

Headrick, R.H., Lynch, J.F., Apel, J., Badiey, M., Chiu, C.-S., Finnette, S., Orr, M., Pasewark. B., Turgut, A., Wolf, S., Kemp, J., Newhall, A., von der Heydt, K., and Tielbuerger, D. (SWARM Group), "Acoustic Normal Mode Fluctuation Statistics in the 1995 SWARM Internal Wave Scattering Experiment," *Journal of the Acoustical Society of America,* submitted and revised, 1998.

CONFERENCE PRESENTATIONS:

Chiu, C.-S., "Realistic Simulation Studies of Acoustic Signal Coherence in the Presence of an Internal Soliton Wavepacket," IOS/WHOI/ONR Internal Solitary Wave Workshop, Victoria, Canada, 27-29 October 1998.

Chiu C.-S., Lynch, J.F., Gawarkiewicz, G., Miller, C.W., and Sperry, B., "Tomographic Maps of the New England Shelfbreak Front," Ocean Science Meeting, San Diego, CA, February 1998.

THESIS DIRECTED:

Miller, C.W., "Estimating the Acoustic Modal Arrivals Using Signals Transmitted from Two Sound Sources to a Vertical Line Hydrophone Array in the 1996 Shelfbreak PRIMER Experiment," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREA: Sensors, Battlespace Environments

KEYWORDS: Littoral, Acoustics, Nowcast, Shelfbreak Fronts

ENVIRONMENTAL EFFECTS ON NAVAL WARFARE SIMULATIONS

Peter C. Chu, Associate Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVE: This is a three-year interdisciplinary and multi-institutional project pursued collaboratively among the NPS Naval Ocean Analysis and Prediction (NOAP) Lab, the NPS Wargame Lab, NAVOCEANO Ocean Modeling Division, and the Army's Coastal Engineering Research Center (CERC). The purposes of the project are (1) to investigate environmental effects on the joint warfare simulations at various scales (e.g., theater level, technical level) and to incorporate the Navy's Meteorological and Oceanographic (METOC) data and models effectively into the joint warfare simulation models, such as RESA and mine warfare models obtained from COMMINWARCOM; (2) to estimate the value added of knowing the METOC data; and (3) to quantitative analyze the value added of knowing the environment and to identify the measure of effectiveness of METOC knowledge.

SUMMARY: (1) Mine Counter-Measure Simulation System (MCM96) from COMMINWARCOM was installed and tested in the NPS Secure Computing and Simulation Laboratory. Various environmental effects on the mine counter-measure have been obtained. (2) MCM96 was investigated under different METOC conditions. The results were presented as an invited paper at the Third International Symposium on Technology and the Mine Problem, Monterey, California, 6-9 April 1998. (3) METOC module was established for the Navy's Research, Evaluation, and Systems Analysis (RESA) wargame (theater level simulation). The module was applied to the Korea Peninsula region simulation. The weather scenario was part of the NPS Wargaming Lab for the instruction purpose. (4) A quantitative analysis scheme (entropy) was established to estimate the value added of knowing the METOC data and to identify the measure of effectiveness of METOC knowledge. These results were presented as an invited paper at the 66th Military Operations Research Society Symposium, Naval Postgraduate School, Monterey, California, 10-12 June 1998. (5) METOC module were started for joint M&S models such as Joint Simulation Systems (JSIMS) and Joint Conflict and Tactical Simulation (JCATS). (6) A joint research effort was established on METOC information in mine warfare with the Royal Navy, UK.

PUBLICATION:

Chu, P.C., Gottshall, E., and Halwachs, T.E., "Meteorological and Oceanographic (METOC) Support for Determining Safe Current in Magnetic Sea Mine Sweeping," *Third International Symposium on Technology and the Mine Problem* (CD-ROM), 6 pp., 1998.

CONFERENCE PRESENTATIONS:

Chu, P.C., "Meteorological and Oceanographic (METOC) Support For Determining Safe Current in Magnetic Sea Mine Sweeping," Third International Symposium on Technology and the Mine Problem, Monterey, CA, 6-9 April 1998.

Chu, P.C. and Gottshall, E., "METOC Support for Mine Countermeasure," 66th Military Operations Research Society Symposium, Monterey, CA, 10-12 June 1998.

Chu, P.C., "Joint Simulation System (JSIMS) Maritime METOC Component," Maritime Integrated Training Architecture, Stennis Space Center, MS, 21-22 September 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Other (Environment Effects)

KEYWORDS: Modeling and Simulation

MINE IMPACT BURIAL MODEL SENSITIVITY STUDY

Peter C. Chu, Associate Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVE: The Mine Impact Burial Model has been developed by the Coastal System Station; subsequent upgrades have been made by the Naval Research Laboratory (NRL). Some of the major input parameters to the model are environment (sedimentation, shear strength, water depth), mine characteristics (shape, center of gravity, weight, and mine deployment parameters), deployment platform (ship, aircraft, submarine), speed of platform, angle of mine upon entering water, rotational velocity at time of deployment and others. The model has undergone limited validation in "R&D" experiments where most input parameters were carefully measured or monitored. Many of the input parameters will never be known for operational mine deployments; thus, even if the model is accurate using "perfect" input parameters, it may not be useful if mine impact burial is sensitive to parameters than are seldom known in practice. The purpose of the effort described in this statement of work is to perform sensitivity tests with the model to evaluate which are the most critical input parameters necessary for accurate mine impact burial prediction.

SUMMARY: One of the parameters believed to be critical for impact burial prediction is shear strength of the sediment. This is rarely known. NAVOCEANO developed sediment databases for many shallow water regions. Shear strength can be inferred from sediment type (with large errors for fine-grained sediments). The model sensitivity to shear strength is important to know in order to determine the usefulness of NAVOCEANO's sediment databases for mine impact burial prediction. Other parameters that will never be known are mine development details such as angle of deployment, rotational velocity of mine, etc. These will be important factors to loop on for model runs. LT Vicki Taber is working on these problems under the guidance of the principal investigator for her master's degree.

PUBLICATIONS:

Chu, P.C., Gottshall, E., and Halwachs, T.E., "Meteorological and Oceanographic (METOC) Support for Determining Safe Current in Magnetic Sea Mine Sweeping," *Third International Symposium on Technology and the Mine Problem (CD-ROM)*, 6 pp., 1998.

Chu, P.C., Chen, Y.C., and Lu, S.H., "Temporal and Spatial Variabilities of Japan Sea Surface Temperature and Atmospheric Forcings, *Journal of Oceanography*, 54, pp. 273-384, 1998.

Chu, P.C., Fan, C.W., Lozano, C.J., and Kerling, J., "An AXBT Survey of the South China Sea," *Journal of Geophysical Research*, 103, pp. 21637-21652, 1998.

Chu, P.C., "Toward Accurate Coastal Ocean Prediction," *Naval Research Review,* L, pp. 31-37, 1998.

CONFERENCE PRESENTATIONS:

Chu, P.C., "Meteorological and Oceanographic (METOC) Support for Determining Safe Current in Magnetic Sea Mine Sweeping," Third International Symposium on Technology and the Mine Problem, Monterey, CA, 6-9 April 1998.

Chu, P.C. and Gottshall, E., "METOC Support for Mine Countermeasure," 66th Military Operations Research Society Symposium, Monterey, CA, 10-12 June 1998.

Chu, P.C., "Joint Simulation System (JSIMS) Maritime METOC Component," Maritime Integrated Training Architecture, Naval Oceanographic Office, Stennis Space Center, MS, 21-22 September 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Other (Environment Effects)

KEYWORDS: Mine Burial, Shear Strength, Ocean Survey, Ocean Variability

GLOBAL POSITIONING SYSTEM (GPS) ANTARCTIC LANDING SYSTEM: LANDING SYSTEMS COMMITTEE STUDIES

James R. Clynch, Research Professor
Department of Oceanography
Sponsor: Space and Naval Warfare Systems Center-Charleston

OBJECTIVE: The aircraft landing system at the U.S. bases in Antarctica must be replaced in the next few years. The Global Positioning System (GPS) is the primary candidate system for use in this remote site. There are several special features about the local environment in polar latitudes that must be studied and validated before flight safety can be assured.

SUMMARY: The technical capability of a differential GPS system to meet the landing requirements in Antarctic has been demonstrated in an ongoing effort over five years. During 1998 the effort focused on following the FAA specification development process for the Local Area Augmentation System (LAAS) and assisting in development of a plan for testing the Mobile Microwave Landing system (MMLS) during the 1998/1999 season. In conjunction with the Space and Naval Warfare Systems Center, San Diego Dr. Clynch developed two small tilt meter systems. One was attached to the MMLS antenna for documentation of the alignment during operations. This unit radioed its measurements to a PC in a benign environment to be logged at 4 Hz. The second tiltmeter was mounted in a small standalone unit that was placed at the end of the runway during the landings of C5 aircraft. Three C5 landings were recorded and a wave in the ice sheet measured. This was just below the level of concern for disturbing the MMLS alignment. The data from the MMLS antenna will be returned in 1999 and analyzed.

During the year Dr. Clynch attended two RTCA committee meetings on GPS landing systems, and participated in two meetings at Charleston, SC. He also attended two GPS technical meetings to stay abreast of the civilian technology.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Electronics, Sensors

KEYWORDS: GPS, Aircraft Landing Systems

GLOBAL POSITIONING SYSTEM (GPS) TRAJECTORY AVERAGING

James R. Clynch, Research Professor
Department of Oceanography
Beny Neta, Professor
Richard Franke, Professor
Department of Mathematics
Sponsors: National Imagery and Mapping Agency and Naval Postgraduate School

OBJECTIVE: The error in GPS positions consists of two primary parts, a random error assumed to have a Gaussian distribution, and a slowly varying bias dependent upon the satellites from which the GPS receiver obtains its data and their configuration. The latter changes abruptly when a different configuration of satellites is used. The objective of this investigation is to devise techniques for estimating the two errors by using multiple trajectories obtained with GPS receivers in the Precise Position System along roads and then obtain an average trajectory.

SUMMARY: Numerous independent sets of data have been obtained. The steps in carrying out the required tasks are: partition sets of data into pieces that correspond to a particular part of a roadway and that have been taken using a single satellite configuration, select a portion of that path to be fit by a straight line or by a parametric cubic curve with continuous tangent vector, and compare the curves obtained for independent sets of data over the same path to estimate the bias vector between the two. When these steps are performed for many independent tracks an estimate of the true bias can be obtained. Matlab programs have been written that perform each of the above tasks.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: GPS, Bezier Curves, Bias Estimation, Curve Fitting, Track Averaging

GLOBAL POSITIONING SYSTEM (GPS) SHIP REFERENCE SYSTEM

James R. Clynch, Research Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to design and validate a GPS system to be used as a Differential GPS (DGPS) reference station on a ship at sea.

SUMMARY: This project is to establish the techniques necessary to achieve a 2 m or better absolute position on a ship using precise positioning system GPS receivers and other sensors. It is anticipated that the receivers will have to be run from atomic clocks and that an inertial system may be required. Once the system has been initialized, the position should be held to sub-meter accuracy. That is, the 2-meter level initialization errors will be biases in the operational position.
During 1998 the data from a 1997 at sea experiment were analyzed. The results of the 1997 sea test were reported at the ION GPS-98 conference. A second experiment was carried out with equipment similar to an operational system. The 1997 experiment used 3 PPS geodetic receivers and three standard geodetic receivers. All data was converted to PPS for analysis in postprocessing. The errors were isolated into broadcast ephemeris errors (both position and clock) and local multipath errors. The temporal characteristics of both were determined. It was found that even on very short baselines, multipath can be averaged down using multiple antennas. It was found that the broadcast ephemeris error could be reduced to 0.7 m with a linear model and 0.3 m with a quadratic model in time. A local Rb oscillator was used in these experiments. It was found that the error from this could be reduced to 0.3 m with averaging. A simple model of a shipboard system was developed using these values. It was found that the overall error might be driven to 1 m level with a days averaging. It should be possible to maintain this error level using phase data to propagate the solution and estimating ephemeris and clock biases before use. The problem of aliasing of the estimates needs to be studied using the 1998 data.

PUBLICATION:

Clynch, J.R., "Error Sources and Their Mitigation for PPS Shipborne Systems," *Proceedings of the ION GPS-98*, p. 551, Nashville, TN, 15-18 September 1998.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Global Positioning System, GPS, Differential GPS

PHYSICAL OCEANOGRAPHIC CONDITIONS OFF CENTRAL CALIFORNIA IN 1998

Curtis A. Collins, Professor
Department of Oceanography
Sponsors: National Science Foundation, Scripps Institution of Oceanography, and University of California-San Diego

OBJECTIVE: The objective of this project is to determine the effects of the 1997-8 El Niño on the surface and subsurface waters of the California Current System off Central California.

SUMMARY: National Science Foundation funds provided for collection of hydrographic data along a line of stations designated as CalCOFI Line 67 which extends from Moss Landing to a distance of about 200 n. miles offshore. It included cruises on the NOAA Ship *McArthur*, 14-17 April, and the R/V *New Horizon*, 21-23 March and 22-25 August. Observations consist of conductivity, temperature, depth (CTD) soundings, vessel mounted ADCP data, nutrient analyses and zooplankton tows. Collaborators include Francisco Chavez and Russ Hopcroft of MBARI. The data collection efforts were designed to complement 1997 observations as well as historical data collected by the California Cooperative Oceanic Fisheries Investigations. The data collected during other 1998 cruises were studied in order to characterize the effect of the 1997-1998 El Niño on Central California waters.

Funding from Scripps provided for participation of NPS personnel in hydrographic surveys of Central California waters on R/V *New Horizon* in May and November 1998. These surveys were designed to build a modern littoral database for coastal waters for use in U.S. Navy operations. NPS also provided a bottom mounted acoustic doppler current profiler (ADCP) for collection of time series data. In May, a 300 kHz narrow band ADCP was used for short-term data collection at three Central California sites. In November, a 300 kHz broad band ADCP was deployed off Davenport, CA, in 125 m of water.

The surface layer was strongly affected by local upwelling associated with both northwesterly winds and springtime acceleration of the equatorward flow in the California Current. Below about 150 m, water properties were associated with poleward flowing equatorial waters, especially over the continental slope. The poleward flow resulted in deepening of isopycnals toward the west and the poleward flows resulted in warmer and more saline water on these isopycnals as contrasted to the subarctic waters found offshore. In early 1998, the warm and saline waters associated with El Niño conditions were replaced with waters that were cooler and fresher.

PUBLICATIONS:

Lynn, R.J., Baumgartner, T., Collins, C.A., Garcia, J., Hayward, T.L., Hyrenback, K.D., Mantyla, A.W., Murphree, T., Shankle, A., Schwing, F.B., Sakuma, K.M., and Tegner, M.J., "The State of the California Current, 1997-1998: Transition to El Niño Conditions," CalCOFI Reports 9-25, 1998.

CONFERENCE PRESENTATIONS:

Dugdale, R., Collins, C., Wilkerson, F., and Marchi, A., "Effects of San Francisco Bay on Surface Region Nutrients in Northern California Coastal Waters; A Comparison of 1997 and 1998 Non El Niño and El Niño Conditions," 1998 Annual Meeting, Eastern Pacific Oceanic Conference, Timberline, OR, September 1998.

Asanuma, H., Chavez, F., Collins, C., Michisake, R., and Rago, T., "The California Current System off Central California, 1997-8, Fall National Meeting, American Geophysical Union, San Francisco, CA, 6-10 December 1998.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: California Current System, Subsurface Ocean Circulation, El Niño

LONG-TERM MONITORING OF CIRCULATION AND SEDIMENT-TRANSPORT PATTERNS NEAR THE SAN FRANCISCO DEEP-OCEAN DISPOSAL SITE

Curtis A. Collins, Professor
Steven R. Ramp, Research Professor
Department of Oceanography
Sponsor: Environmental Protection Agency

OBJECTIVE: The Environmental Protection Agency (EPA) has designated a deep-water site on the continental slope off San Francisco as a disposal site for dredge material from the greater San Francisco Bay. This was the first deep-ocean disposal site in the nation and requires a program of long-term monitoring of the site to determine environmental effects. Moorings to measure the movement of water and resuspended material near the disposal site were made during the period November 1997 to November 1998.

SUMMARY: Moorings were deployed at three locations at and near the deep ocean disposal site on November 11-12, 1997, and recovered on November 3-6, 1998. Moorings included upward looking acoustic doppler current meters at 100 m depth and standard current meters at 225, 400, 800, 2000 m, and 50 m above the bottom. Sediment traps were included at mid-depth (200 and 395 m) and near bottom. A near-bottom package consisting of vector-averaging current meters, temperature gradient measurements, and a transmissometer was included. A failed Monterey Bay Aquarium Research Institute

(MBARI) mooring was also recovered on the November 1998 cruise. This is a joint project with Dr. Marlene Noble, U.S. Geological Survey.

PUBLICATIONS:

Noble, M. and Ramp, S.R., "Moored Observations of the Structure and Variability of the California Undercurrent Off the Farallon Islands, CA," *Deep-Sea Research II*, 1999, in press.

Steger, J.M., Collins, C.A., Schwing, F.B., Noble, M., Garfield, N., and Steiner, M.T., "An Empirical Model of the Tidal Currents in the Gulf of the Farallones," *Deep-Sea Research, II*, 45, pp. 1471-1505, 1998.

Steger, J.M., Schwing, F.B., Collins, C.A., Rosenfeld, L.R., Garfield, N., and Gezgin, E., "Seasonal Variability of the Circulation and Water Masses in the Gulf of the Farallones, *Deep-Sea Research II*, submitted.

DoD KEY TECHNOLOGY AREA: Other (Environmental Remediation)

KEYWORDS: California Current, Gulf of the Farallones, Ocean Disposal

LAGRANGIAN STUDIES OF SUBMESOSCALE COHERENT VORTICES IN THE CALIFORNIA CURRENT SYSTEM

Curtis A. Collins, Professor
Newell Garfield, Research Assistant Professor
Robert Paquette, Emeritus Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: Along the Central and Northern California coast, subsurface floats routinely encounter submesoscale coherent vortices. The occurrence of these vortices is common enough that they have an important role in the offshore transport of properties from the coastal zone to the deep sea. The specific objectives of this study are to determine (1) when, where, and how these vortices are formed, and (2) their role in mixing and transporting equatorial and subarctic waters.

SUMMARY: In both May and November, 1998, a triad of RAFOS floats were launched in poleward flow over the middle of the continental slope to the south of 36°N. Subsequently, hydrographic surveys were carried out along the Central California coast between 36°N and 38°N. The hydrographic surveys revealed a submesoscale feature only at Davidson seamount.

Six floats that were launched in 1997 surfaced. These data were processed and the floats navigated. The resulting trajectories showed two unusual features. Floats that were launched in poleward flow south of Point Sur left the coast at Point Sur and moved westward for the remainder of their mission. Floats launched north of Point Sur were carried far to the north—one float surfaced near 48°N. The latter indicates strong, sustained poleward flow along the West Coast of the U.S. in 1997, consistent with our understanding of observed El Niño conditions.

Sources off Point Arguello, Moss Landing, and Cape Mendocino were monitored using the NPS Ocean Acoustic Observatory at Point Sur. There was also collaboration with scientists at Los Alamos National Laboratory (LANL) to study the behavior of "numerical" floats in their high-resolution numerical ocean model.

PUBLICATIONS:

Chereskin, T.K., Morris, M.Y., Niiler, P.P., Kosro, P.M., Smith, R.L., Ramp, S.R., Collins, C.A., and Musgrave, D.L., "Spatial and Temporal Characteristics of the Mesoscale Circulation of the California Current from Eddy-Resolving Moored Measurements," *Journal of Geophysical Research*, submitted.

Collins, C.A., Garfield, N., Paquette, R., Rago, T., and Carter, E., "Subsurface Lagrangian Measurements in the Northeastern Pacific Ocean," *Naval Research Review*, L, (2) pp. 20-23, 1998.

Collins, C.A., Garfield, N., Rago, T.A., Rischmiller, F.W., and Carter, E., "Mean Structure of the Inshore Countercurrent and California Undercurrent Off Point Sur, California," *Deep-Sea Research II*, in press.

Garfield, N., Collins, C.A., Paquette, R.G., and Carter, E., "Lagrangian Exploration of the California Undercurrent, 1992-1995," *Journal of Physical Oceanography*, in press.

Steger, J.M., Collins, C.A., and Chu, P.C., "Circulation in the Archipelago de Colon (Galapagos Islands), November 1993," *Deep-Sea Research II*, 45(6) pp. 1093-1114, 1998.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: California Current System, Subsurface Ocean Circulation, Mesoscale Ocean Variability

SIMULATION OF LAGRANGIAN DRIFTERS IN THE LABRADOR SEA

Roland W. Garwood, Jr., Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The long-term goals of the Oceanic Planetary Boundary Layer (OPBL) Laboratory at the Naval Postgraduate School (NPS) are to understand the role of the OPBL in exchanging momentum, mass, and energy between the ocean and the atmosphere, and to build and verify realistic models for OPBL processes in ocean circulation and air-sea interactions. The purpose of this study is to understand the motion and sensor response of drifting packages of scientific instruments in the Office of Naval Research's Accelerated Research Initiative (ARI) on Deep Oceanic Convection in the Labrador Sea (Labrador Sea Group, 1998). Understanding the drifter response will lead to optimal strategies for deployment of drifting instruments, and it will help in the interpretation of observations obtained by instruments under the influence of oceanic convection. A key scientific objective is to understand the turbulent kinetic energy budget for free and forced deep oceanic convection, and the processes leading to deep penetrative convection in subpolar seas.

SUMMARY: The method is to use nonhydrostatic oceanic large-eddy simulation (LES) to predict the unsteady three-dimensional turbulent velocity, temperature, salinity, and pressure fields on a model grid. Typical grid domains are 1-4 km deep by 3-12 km horizontally, resolving the OPBL turbulence from the integral scale (dominant turbulent eddy size) into the inertial range. These fields are archived or used directly to advect Lagrangian drifter models (LDMs). LDMs are designed to simulate a variety of drifter designs: pure Lagrangian, isobaric, glider, or propelled autonomous underwater vheicles (AUVs).

A major milestone passed during FY98 was the large-eddy simulation of Labrador Sea convection during the 28-day ship-observed focus period of the 1997 field experiment. Simulation of Lagrangian and isobaric drifters was conducted simultaneously. Model-generated data sets of the statistics for the flow fields, thermodynamic variables, and drifter trajectories have been archived for analysis.

Earlier results for idealized steady-state convection (Harcourt, et al., 1998), which neglected entrainment, have been shown to hold for the realistic unsteady simulation of the Labrador Sea during winter 1997. These results show clearly that isobaric (Rossby-type) drifters will sense mean fields for temperature and velocity that will be biased by the tendency for the fixed-depth drifters to seek out and maintain position in zones of horizontal convergence. Depending upon the ballasting depth, these drifters will experience a significant mean vertical velocity that is caused by the turbulence, not by a mean upwelling/downwelling. Although the Labrador Sea isobaric drifters deployed during the 1997 winter did not perform as designed, the LES-predicted biases have been confirmed by isobaric drifters released into the Greenland Sea (Gascard, personal communication; Lherminier, 1998).

These LES results have yielded several important new findings including:

- The horizontal turbulent kinetic energy (TKE) is surprisingly large, compared with the vertical TKE for deep Labrador Sea convection. The reason is the large shear production of horizontal TKE near the surface that is subsequently transported vertically.
- The amount of penetrative convection is considerable. The entrainment zone is a negative buoyancy flux region that is frequently 100-200 m thick, below the well-mixed layer. An important new finding is the role of pressure transport in energizing the stable layers below the turbulence. Pressure transport, unlike turbulent transport, may penetrate hundreds of meters into the pycnocline below the well-mixed turbulent layer.
- Variance in temperature is dominated by entrainment, not by the surface heat flux, even though the surface heat flux usually exceeds the entrainment heat flux. The large variances in both temperature and salinity predicted by LES suggest that much of the patchiness observed in conductivity, temperature, depth (CTD) profiles during the 1997 field experiment is explained by local forcing.
- Planetary rotation has significant effects upon the TKE and upon entrainment. None of the simulations of Labrador Sea deep convection were found to be realistic without both horizontal and vertical Coriolis components. This shows clearly the need to include rotation in mixed-layer models for convection (Garwood, 1991; Garwood, et al., 1985). Improved mixed layer parameterization for both dissipation and pressure redistribution will lead to improved mixed layer performance for basin-scale ocean models.

There are important implications for Naval Oceanography. First, results concerning the advection of freely-drifting bodies have direct implications for all drifting material in the ocean (Garwood, et al., 1998), including suspended matter and plankton that affect the optical properties of seawater. Second, LES has important future application in the shelf and nearshore regions because of the need to include nonhydrostatic acceleration over ocean topographic features having horizontal scales less than a few kilometers. Thirdly, LES can help explain the ocean surface's radar signature (Fischer, et al., 1998), as well as the other surface properties detected by remote sensing.

PUBLICATIONS:

Fischer, K.W., Legg, S., Munk, W.H., Schuman, R.A., Garwood, R.W., Jr., and Palshook, J.P., "Modeled Radar Surface Signatures in Deep Ocean Convection," *IEEE Transactions on Geoscience and Remote Sensing*, 1998, in press.

Garwood, R.W., Jr., Harcourt, R.R., and Stone, R.E., "Simulation of Drifters in a Turbulent Ocean," *Naval Research Reviews*, Vol. L, K.L. Davidson (ed.), pp. 8-12, 1998.

Garwood, R.W., Jr., Jiang, L., and Harcourt, R., "Simulating the Response of Drifters to Deep Convection," *High Performance Computing*, DoD High Performance Computing Modernization Office, Arlington, VA, May 1998.

Harcourt, R., Jiang, L., and Garwood, R.W., Jr., "Numerical Simulation of Drifters Response to Labrador Sea Convection," Naval Postgraduate School Technical Report, NPS-OC-98-001, February 1998.

The Labrador Sea Group, "The Labrador Sea Deep Convection Experiment," *Bulletin of the American Meteorological Society*, 79, pp. 2033-2058, 1998.

CONFERENCE PRESENTATIONS:

Bramson, L.S., Guest, P.S., and Garwood, R.W., Jr., "The Effect of Atmospheric Forcing on the Labrador Sea Mixed Layer in the Winter of 1997," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, 9-13 February 1998.

Garwood, R.W., Jr. and Harcourt, R., "Large-Eddy Simulation of Labrador Sea Winter Deep Convection, Part I: Turbulent Kinetic Energy and Temperature and Salinity Variances," American Geophysical Society Ocean Sciences Meeting, San Diego, CA, 13 February 1998.

Harcourt, R. and Garwood, R.W., Jr., "How Does Planetary Rotation Influence Deep Water Formation?" American Geophysical Union Fall Meeting, San Francisco, CA, 7 December 1998.

Harcourt, R. and Garwood, R.W. Jr., "Large-Eddy Simulation of Labrador Sea Winter Deep Convection, Part II: Simulation of Drifter Response to Deep Convection," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, 13 February 1998.

Harcourt, R. and Garwood, R.W. Jr., "Fast, Deep, and Out of Control: Rotational Scaling of Turbulent Velocities and Entrainment," Labrador Sea Experiment Workshop, Big Fork, MT, 11 September 1998.

THESIS DIRECTED:

Stougard, Pegeen O'Neil, "The Role of Salinity in Equatorial Mixed Layers," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREA: Battlespace Environments, Environmental Quality, Sensors, Modeling and Simulation, Other (Oceanography)

KEYWORDS: Air-Sea Interactions, Ocean Convection, Lagrangian Drifters

TROPICAL OCEAN MIXED LAYER SYSTEM

Roland W. Garwood, Jr., Professor
Arlene A. Guest, Oceanographer
Department of Oceanography
Sponsors: National Oceanic and Atmospheric Administration and the National Science Foundation

OBJECTIVE: The scientific objective of this four-year study was to understand the response of the tropical and equatorial ocean turbulent boundary layer system to unsteady atmospheric forcing on time scales from diurnal to annual. This helps advance the long-term goal of the Oceanic Planetary Boundary Layer (OPBL) Laboratory to improve and verify a generalized mixed layer/entrainment zone parameterization for Ocean Global Circulation Models (OGCM) that is physically consistent and globally valid.

SUMMARY: As part of the international Tropical Oceans Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE), a hierarchy of numerical models from the scale of the turbulence itself to the entire Pacific basin scale was developed and used to understand the tropical ocean mixed layer system. In this last year, results from previous years were synthesized and expanded, and attention was focused on the role of precipitation in the tropical ocean mixed layer of the Pacific Ocean.

The NPS mixed layer model with enhanced entrainment zone parameterization was used to simulate a 15-day period during the Intensive Observation Period (IOP) of TOGA-COARE using observed meteorological forcing. Guest, et al. (1998) demonstrated that time-varying precipitation, winds and diurnal heating need to be included for accurate model simulations. Numerical simulations that neglect precipitation effects will result in overly deep mixed layers and thus inaccurate sea surface temperatures and ocean heat storage.

The basin scale OGCM, which has the NPS mixed layer model embedded, has been used to demonstrate the importance of the entrainment zone parameterization in improving the sea surface temperature distribution and vertical distribution of heat. In addition, the mesoscale waves and eddies modulate the entrainment zone activity, with the entrainment zone mixing depending on the shear enhancement or reduction attributable to the mesoscale motion.

The Large-Eddy Simulation (LES) model, which predicts the unsteady three-dimensional turbulence itself, was used to examine the response of the mixed layer temperature and salinity patchiness to westerly wind bursts (Garwood, et al, 1998). Variances of temperature and salinity fields are a measure of the intensity of the patchiness. A variety of hypothetical cases as well as a case study during the IOP were analyzed. Some of the findings are:

(1) If there is little or no precipitation, and the upper pycnocline is dominated by temperature, then the entrainment heat flux contributes more to the temperature variance production in the mixed layer than does the surface heat flux.
(2) If there is precipitation in the above case, then the production of temperature variance will tend to decrease because of reduced entrainment.
(3) If the salinity stratification compensates for the thermal stratification at the base of a deepening mixed layer, then the salinity variance and patchiness is greatest.
(4) The spatial scale of the patchiness is related to the depth of mixing, with deeper mixed layers having larger-diameter convection cells and horizontal rolls than a more shallow mixed layer. These organized structures, which are well-predicted by LES, dominate the spatial scale of the variances.

This work has important implications for global and climate modeling efforts, and in particular for coupled ocean-atmosphere models. While the details of the turbulence itself are parameterized in OGCM's, the necessity for including realistic time-varying forcing of precipitation as well as winds and diurnal heating have been demonstrated. The scales of the patchiness predicted by the LES control the temporal and spatial scales of air-sea interactions. In addition, the intermittent capping of the ocean mixed layer by precipitation plays a role in the biological productivity and the stability of the ecosystem in the tropical euphotic zone.

PUBLICATIONS:

Garwood, Roland W., Jr., Guest, A.A., and Stougard, P.O., "Response of Mixed-Layer Temperature and Salinity Patchiness to Westerly Wind Bursts," *Proceedings of COARE98*, WCRP Report, 1999, in press.

Guest, A.A., Stougard, P.O., and Garwood, R.W., Jr., "The Response of the Ocean Mixed Layer to Surface Forcing Events," *Proceedings of COARE98*, WCRP Report, 1999, in press.

Harcourt, R., Jiang, L., and Garwood, R.W., Jr., "Numerical Simulation of Drifters Response to Labrador Sea Convection," Naval Postgraduate School Technical Report, NPS-OC-98-001, February 1998.

CONFERENCE PRESENTATIONS:

Garwood, Roland W., Jr., Guest, A.A., and Stougard, P.O., "Response of Mixed-Layer Temperature and Salinity Patchiness to Westerly Wind Bursts," CLIVAR/GEWEX COARE98 Conference, Boulder, CO, 7-14 July 1998.

Guest, A.A., Stougard, P.O., and Garwood, R.W., Jr., "The Response of the Ocean Mixed Layer to Surface Forcing Events," CLIVAR/GEWEX COARE98 Conference, Boulder, CO, 7-14 July 1998.

OTHER:

"NPS Mixed Layer Model" code has been requested and distributed to a variety of international researchers and is now available for interactive use via a web-based interface (http://www.oc.nps.navy.mil/opbl/).

THESIS DIRECTED:

Stougard, Pegeen O'Neil, "The Role of Salinity in Equatorial Mixed Layers," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation, Other (Oceanography)

KEYWORDS: Ocean Turbulence, Tropical Air-Sea Interactions, Ocean Mixed Layer

POLAR SEA CONVECTIVE INSTABILITIES

Roland W. Garwood, Jr., Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The major scientific objective of this five-year study is to understand the coupled ocean mixed layer-ice system response to the passage of atmospheric storms.

SUMMARY: The most intense surface cooling and wind stresses in the Arctic are associated with storms, and their long-term cumulative effects on the heat and water budgets for the Arctic Ocean are predicted by including (i) realistic mixed layer physics, (ii) ice thermodynamics, and (iii) three-dimensional wind-driven ocean circulation.

Previous work showed that oceanic instabilities may lead to significant deep oceanic convection and possible formation of bottom water. The initial energy source to trigger these instabilities may be provided by transient atmospheric forcing. Numerical models are being developed including a three-dimensional simulation of the upper ocean (temperature, salinity, circulation, and ice) response to passage of atmospheric storms. This numerical model consists of an existing ocean primitive equation model with embedded turbulence-closure mixed layer and an ice model with realistic thermodynamics and mechanical properties. The embedded mixed layer includes previously-neglected physics to predict the onset of conditional instabilities and possible formation of deep water.

The realistic prediction of deep convection is necessary to understand the start of the global conveyor belt and the role of the oceans in climate change. A major deficiency in earlier ocean models has been the lack of adequate convection physics to realistically predict the correct temperature and salinity properties for the convectively-produced deeper water masses. The modeling program, including realistic storm forcing and realistic ocean convection directly ties atmospheric forcing and ice thermodynamics to mixed layer dynamics and the start of the global conveyor belt in the Greenland-Iceland Seas.

The results are leading to more realistic parameterization of subgrid convection of heat, mass, momentum, nutrients, and tracers in basin and global oceanic models.

PUBLICATIONS:

Fischer, K.W., Legg, S., Munk, W.H., Schuman, R.A., Garwood, R.W. Jr., and Palshook, J.P., "Modeled Radar Surface Signatures in Deep Ocean Convection," *IEEE Transactions on Geoscience and Remote Sensing*, 1998, in press.

Garwood, R.W., Jr., Harcourt, R.R., and Stone, R.E., "Simulation of Drifters in a Turbulent Ocean," *Naval Research Reviews*, Vol. L, K. L. Davidson, (ed.), pp. 8-12, 1998.

CONFERENCE PRESENTATIONS:

Harcourt, R. and Garwood, R.W., Jr., "How Does Planetary Rotation Influence Deep Water Formation?" American Geophysical Union Fall Meeting, San Francisco, CA, 7 December 1998.

Stone, R., and Garwood, R.W., Jr., Guest, P.S., and Harcourt, R., "1-D Modeled Temperature Variance Compared to Greenland Sea Drifter Data," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, 9-13 February 1998.

Stone, R., Garwood, R.W., Jr., and Harcourt R., "Simulation of Thermobaric Plumes," American Geophysical Union Fall Meeting, San Francisco, CA, 7 December 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Sensors, Modeling and Simulation, Other (Oceanography)

KEYWORDS: Air-Sea-Ice Interactions, Deep Ocean Convection, Climate

WAVE EVOLUTION ON THE CONTINENTAL SHELF

Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The main objective of this project is to evaluate the energy balance of wind-generated waves in shallow water.

SUMMARY: In this project the spectral energy balance of windwaves on the continental shelf will be evaluated with a field experiment scheduled to take place off Duck, NC, in the fall of 1999. Preparations are underway for the deployment of a coherent array of five internal recording bottom pressure sensors and five directional wave buoys in depths ranging from 20-40 m. The measurements will be used to verify theoretical predictions of nonlinear spectral energy transfers and estimate wave energy losses resulting from bottom friction and whitecaps.

CONFERENCE PRESENTATIONS:

Herbers, T.H.C., Hendrickson, E.J., and O'Reilly, W.C., "Propagation of Swell Across a Wide Continental Shelf," Waves in Shallow Water Environments Meeting, Leuven, Belgium, May 1998.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Wave Breaking, Bottom Friction, Continental Shelf

SPATIAL COHERENCE AND CREST-LENGTH STATISTICS OF WAVES IN DEEP WATER

Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to determine how nonlinearity and directional spreading affect the spatial coherence and crest-length statistics of ocean surface waves.

SUMMARY: This project is part of the ONR Mobile Offshore Base (MOB) Program in which the feasibility of a large floating platform in deep water is examined. A major concern is the platform response to extreme wave conditions. The specific task of this project is to determine the spatial coherence of natural wind-generated ocean waves over distances of O(1 km) (i.e., nominal platform dimensions). Work is in progress to numerically simulate two-dimensional sea surfaces based on weakly nonlinear wave theory, and estimate wave crest-length statistics from the simulated sea surfaces. This project is a collaboration with Dr. Steve Elgar (Washington State University).

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Surface Waves, Spatial Coherence, Wave Crest Lengths

INNER SHELF AND NEARSHORE WAVE TRANSFORMATION

Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is to predict accurately the evolution of surface waves from deep water across the continental shelf to the beach.

SUMMARY: This continuing project is focused on the effects of nonlinear wave-wave interactions and wave breaking on the evolution of wind-wave spectra across the inner continental shelf. A new theoretical model is under development that incorporates the effects of a gently sloping bottom and nonlinear interactions. A directional buoy and an array of nine bottom pressure recorders were deployed on the inner shelf offshore of Duck, NC, during the SandyDuck experiment, to test predictions of nonlinear interactions and estimate energy dissipation rates.

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THESIS DIRECTED:

Borbash, M.I., "Observed Directional Spectra of Shoaling and Breaking Waves," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Continental Shelf

IMPROVED PARAMETERIZATIONS OF TRIAD AND QUARTET INTERACTIONS IN SPECTRAL WIND-WAVE MODELS

Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is to improve the representation of nonlinear wave-wave interactions in operational wave prediction models.

SUMMARY: It is well known that nonlinear wave-wave interactions are poorly represented in current operational wave prediction models (e.g., WAM, SWAN). In this project a team of scientists from the Naval Postgraduate School, the Army Corps of Engineers, David Taylor Model Basin, and Alkyon Hydraulic Consultancy and Research, are evaluating the

shortcomings of existing models and developing and testing new approximations. A numerically efficient technique for computing the energy exchanges between four wave components in quartet interaction was validated through comparisons with exact numerical calculations.

PUBLICATION:

Norheim, C.A., Herbers, T.H.C., and Elgar, S., "Nonlinear Evolution of Surface Wave Spectra on a Beach," *Journal of Physical Oceanography,* 28(7), pp. 1534-1551, 1998.

CONFERENCE PRESENTATIONS:

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Herbers, T.H.C., Russnogle, N.R., and Elgar, S., "Field Observations of the Spectral Energy Balance in the Surf Zone," Waves in Shallow Water Environments Meeting, Leuven, Belgium, May 1998.

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THESIS DIRECTED:

Russnogle, N.R., "Spectral Energy Balance of Waves in the Surf Zone," Master's Thesis, Naval Postgraduate School, March 1998.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Continental Shelf, Beach

MODELING THE RESPONSE OF MONTEREY BAY TO WIND AND TIDAL FORCING

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Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: This is a one-year proposal to apply new technologies to the Navy coastal ocean modeling activities. It includes numerical simulations of the responses of the Monterey Bay (MOB) water circulation to tidal forcing and observed and model atmospheric wind forcing. It also includes validation of the MOB coastal ocean system (COS) developed at the NPS in cooperation with NAVO using numerical grid generation techniques and the Princeton Ocean Model against observations. The project also includes applications of data assimilation techniques to combine the Coastal Applications Radar (CODAR) with the model data in study of this new data type for use in coastal ocean modeling and in the study of the model forecast capability. This is especially important for the MOB region which has extremely steep topography with a submarine canyon and seamounts. With this type of topography no model has ever been tested anywhere. The NPS ocean model (NAM) for the MOB includes data processing routines, a grid generation routine, a grid-model coupling package, data assimilation routines and visualization routines. Its curvilinear, coastline-following (coastline fitted) orthogonal and nearly orthogonal, multi-block grid options represent a new advance in coastal ocean modeling. The MOB COS will be forced with diurnal winds from observation and the NCAR MM5 atmospheric mesoscale model and realistic topography, and observed monthly mean temperature and salinity. The model output will be analyzed, studied and compared against ob-

served tide elevation from a network along the coast. The results of the barotropic tidal model will be used by the 3-D MOB COS to study 3-D tidal current structures.

SUMMARY: The MOB NAM with curvilinear coastline-following (coastline-fitted) nearly-orthogonal grid (multi-block grid code version for a single-block grid), the realistic MOB topography and observational temperature and salinity fields works well for very steep bottom topography. The model runs with the summer MOB observed and mesoscale model (NCAR MM5) winds have been analyzed. The model outputs reproduce key physics such as upwelling and downwelling centers, the right order of magnitude for the coastal current, and temperature and salinity fields in comparison with observational data. Assimilations of the pseudo CODAR data into the MOB NAM using nudging have shown very encouraging result. The global *rms* errors for the u- and v-components reduce stability (*rms* of v-components reduce faster than those of u-components) after 50-day of data insertion. This shows the MOB NAM has a forecast capability using CODAR and nudging. This study needs to be continued for more frequent data inversion and longer insertion period with various weight function to find the best one for this new data type.

A barotropic tidal model was developed for the MOB region. The model has 8 tidal constituents (*M2,S2,N2,K2,K1,O1,P1,Q1*) and realistic topography with 131 by 131 grid points for the MOB region. The model was studied with various open boundary conditions. It has been found that while sea water levels are not too sensitive to open boundary conditions (OBC), tidal currents, as expected, are very sensitive to OBC. Also found was that the classical OBC reproduce reasonable surface elevation, but did not reproduce good tidal current fields. It was additionally found that both may work well for shallow waters where dissipation is large. For the MOB region, the model domain has three OBC with very deep topography and almost no shallow depths, the dissipation is small and reflection is large, the classical OBC do not work well. The classical OBC was modified and the formulation takes into account not only elevation, but also current field. This works better in comparison with the two classical OBC in comparison with tidal data of the Monterey, Santa Cruz stations. Based on the barotropic tidal studies, a baroclinic tidal model is being developed to study the MOB baroclinic tidal current structure.

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Ly, L.N., "On a Numerical Simulation of Summer Circulation for Monterey Bay," Seventh International Conference HYDROSOFT-98, Como, Italy, September 1998.

Ly, L.N. and Luong P., "On Monterey Bay Circulation Simulations," Eighth Annual DoD HPCMO User Group Conference, Orlando, FL, August 1998.

Luong, P. and Ly, L.N., "Advantage of Numerical Grid Techniques in Coastal Ocean Modeling," Eighth Annual DoD HPCMO User Group Conference, Orlando, FL, August 1998.

Ly, L.N. and Luong P., "On Winter Circulation of the South China Sea Using a Coastal Ocean System With Breaking Wave Effects and Numerical Grids," American Geophysical Union Western Pacific Geophysics Meeting, Taipei, Taiwan, July 1998.

Ly, L.N. and Luong P., "NAM Ocean Modeling System Development and an Application to the South China Sea," South China Sea International Workshop, HoChiMinh-City, Vietnam, June 1998.

Ly, L.N. and Luong P., "A Three Dimensional Modeling for the Monterey Bay Circulation," National Oceans Conference, Monterey, CA, 1998.

Ly, L.N., "A Numerical Study of Turbulent Dissipation Rate Under Surface Breaking Waves," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, February 1998.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation, Other (Environmental Effects)

KEYWORDS: Monterey Bay Response, Wind and Tidal Forcing, Nowcast/Forecast System, Air-Sea Interaction, Air-Wave-Sea System, Wind-Wave-Turbulence, Data-Model Combination, Coastal Ocean Modeling, Numerical Grid Generation, Data Assimilation, HF Radar Ocean Currents

MODELING THE LONG-TERM TURBULENT CIRCULATION OF THE ARCTIC OCEAN AND THE SEA ICE

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Yuxia Zhang, Research Associate
Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The overall goal of this project is to develop a state-of-the-art coupled Arctic Ocean-ice model and to integrate this model for long enough time to determine the quasi-equilibrium turbulent circulation of the ice-covered Arctic Ocean as driven by multi-year observed atmospheric forcing and external realistic lateral boundary conditions using advanced parallel computers.

SUMMARY: During the second year of this project, which started in October 1996, the following major tasks have been achieved. A 220-year spin-up integration of the coupled ice-ocean model of the Arctic at resolution of 18 km and 30 levels forced with ECMWF atmospheric forcing for 1990-94 has been completed. Some analysis of the quasi-equilibrium state of the Arctic Ocean and sea ice has been done and it is being published. Model results demonstrate importance of high resolution (both horizontal and vertical) on achieving realistic large-scale ocean and ice circulation patterns, inter-basin exchanges, shelf-basin communication, export of sea ice and fresh water out and import of heat and salt into the Arctic Ocean. Those results compare very favorably with recent observations (e.g., data from submarine cruises, remote sensing, and from hydrological sections). Prior to running a simulation with realistic interannual atmospheric forcing starting in 1979, a 20-year integration using repeated 1979 atmospheric forcing has been completed. As a part of this simulation, the so-called Multiple Active River Tracer Experiment (ARTEX) to study distribution, variability, and budgets of the Arctic Ocean fresh water has been run in parallel. Currently underway is an integration (with the continued ARTEX experiment) using re-analyzed daily atmospheric datasets from ECMWF for 1979-1998. Comparison of results for the 1990s with ones for the 1979 (after 30-year run) shows dramatic changes in large scale circulation, property distribution and export of sea ice and fresh water out from the Arctic Ocean via Fram Strait and the Canadian Archipelago. Some of these results have already been presented atseveral conferences and they are being analyzed for publication. Further improvements in the coupled model will continue in the third year of the project. They will include: high-quality parameterizations of surface exchanges, ice dynamics, near-surface mixing, deep convection, and topographic interactions as well as implementation of a 9-km and 40 level grid and its extension into the North Pacific and North Atlantic. Model results will continue to be analyzed and compared with available and new observations to evaluate the model, to extend interpretation of the data, and to guide future field programs. Significance of this research lies in improving the present understanding of the Arctic Ocean system, to allow applications to biological, geochemical, and climate problems leading to practical predictive ability.

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CONFERENCE PRESENTATIONS:

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Maslowski, W., "Modeling Interannual Variability of the Arctic Ocean and Sea Ice Circulation," 49th Arctic Science Conference, Fairbanks, AK, 25-28 October 1998.

Maslowski, W., "Current State of Arctic Sea Ice - Ocean Modeling," 1st Session of the ACSYS Numerical Experimentation Group Meeting, Kiel, Germany, 16-19 November 1998.

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Murley, S.P., Maslowski, W., Bourke, R.H., Zhang, Y., and Semtner, A.J., "Variability of Fresh Water Export Through Fram Strait and Davis Straits From a High Resolution Model," American Geophysical Fall Meeting, San Francisco, CA, 6-10 December 1998.

HIGH-PERFORMANCE MODELING OF THE ARCTIC OCEAN AND ITS SEA ICE IN TURBULENT EQUILIBRIUM

Wieslaw Maslowski, Assistant Professor
Albert Semtner, Professor
Department of Oceanography
Sponsor: Cray Research, Inc. through the University of Alaska-Fairbanks

OBJECTIVE: To advance understanding of the Arctic Ocean and sea ice circulation by improving the realism of numerical simulations of important physical processes including major ocean currents and eddies resolved for the first time ever. To do this by exploiting the power of massively parallel computers, especially the CRAY T3E at the Arctic Region Supercomputing Center in Fairbanks.

SUMMARY: During the last year of this 3-year project, the high-resolution model of the Arctic Ocean was optimized and it completed a 220-year integration with realistic high frequency atmospheric forcing using the massively parallel CRAY T3E of the Arctic Region Supercomputing Center at the University of Alaska Fairbanks. Improved parameterizations of physical processes important in the Arctic (e.g., the open ocean convection or the elastic-viscous-plastic sea ice rheology) combined with more realistic forcing, high resolution, and proper communications with the world's ocean dramatically improve realism and performance of model simulations and they allow comprehensive synthesis of new and existing data. The thermohaline circulation of the Arctic Ocean has been simulated very realistically. Multiple tracers have been included into the model simulation and they allow study of the fresh water circulation in the shelf seas and communication with the deep ocean, the spreading of waters of Pacific and Atlantic origins, and the distribution of contaminants from the Arctic rivers and shelf regions. Most important findings resulting from this work to date are: (i) major currents in the Arctic Ocean are topographically controlled and they have widths of order 100 km or less suggesting that their adequate representation in a model requires ~10-km grid spacing, (ii) elevated levels of eddy kinetic energy are found in the Beaufort, Labrador, and Nordic Seas and in the North Atlantic, and eddies there significantly contribute to the large scale circulation and property fluxes within and in/out of the Arctic Ocean, (iii) the simulated eddies are of order 100 km suggesting that even more eddy activity is to be expected at higher resolutions, (iv) transports between the North Atlantic and Arctic Ocean compare well with observations but further improvements of physical representation of outflow and overflow regions and their bathymetry are desired, (v) preferred pathways exist for fresh water transport from the shelves into deep basins and out of the Arctic Ocean, and they may vary in response to changes in the atmospheric and sea ice regimes, and (vi) ice thickness and concentration depend not only on the large scale atmospheric and oceanic fields but also on oceanic eddies, especially in marginal ice zones. Some model results have been animated and distributed on video tapes and CD-ROMs. More than 200

CD-ROMs with animations from the river tracer experiments have been distributed world wide to various communities: scientific, K-12, state and federal agencies, libraries and data centers, and commercial institutions. Our model simulations provide unprecedented wealth of new information regarding both large- and regional-scale sea ice and ocean circulations. Many scientific and practical applications can be made with the model. This effort has conclusively demonstrated the power of high-performance Cray computers to solve realistic fluid dynamical problems in oceanography.

PUBLICATIONS:

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CONFERENCE PRESENTATIONS:

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COMPARISONS OF THE LANL POP MODEL AND WOCE OBSERVATIONS

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Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: To validate the very realistic global Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) model with observational data collected during the World Ocean Circulation Experiment (WOCE). This project is ongoing.

SUMMARY: To obtain optimal model output for comparisons with WOCE data, the 1/6-degree POP model was run for the period 1993-1997 extending the run two years and thus providing coincident output with many WOCE observations. Particle trajectory positions, started at the initial positions of WOCE floats, were saved over the duration of the run together with high-frequency output at the locations of WOCE current meters. Evaluations of this new run and the earlier 1/6-degree simulation (1986-1995) have continued in various ocean basins. In the South Atlantic where climatically important interbasin and inter-hemispheric exchanges of water masses take place, a synthesis of model behavior has been constructed. The synthesis revealed a model ocean where central and intermediate waters become warmer and saltier than observations as the equator is approached, and quantities of bottom and intermediate waters that are severely under-represented producing an overturning thermohaline circulation consisting of a balance between surface and deep waters. The overturning component of meridional heat transport dominates the total as in observations, however the magnitude of the total heat transport is somewhat lower than that observed. Water mass pathways through and out of the basin are largely in agreement with those inferred from data. In the Pacific and Indian Oceans potential vorticity, a water mass tracer, calculated from WOCE hydrography was compared with that from the model. Upper water column features showed good agreement. Finally, a new fully global version of POP was run with improved topography and surface forcing (daily ECMWF reanalysis wind stresses, heat and salt fluxes for 1979-1993), and a mixed layer. Initial model evaluations are underway.

PUBLICATION:

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DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Ocean Circulation, Model Validation, Numerical Modeling

DATA ENHANCED MODELING OF SEA AND SWELL ON THE CONTINENTAL SHELF

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Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: To develop and test improved wave propagation and data assimilation methods that are compatible with the coastal wave prediction model SWAN and applicable to a wide range of geographic settings.

SUMMARY: Data assimilation methods are under development for the coastal wave prediction model SWAN. Currently SWAN and similar regional wave prediction models are nested within the global wave prediction model WAM. A drawback of this approach is that initialization errors (e.g., errors in WAM predictions owing to uncertainties in the wind field and inaccuracies in the propagation of waves over large distances) can seriously degrade the coastal model predictions. In this project new methods are implemented to enhance the quality of coastal wave predictions through the assimilation of in-situ (e.g., directional wave buoys) and remotely sensed (e.g., airborne and satellite radar systems) wave data collected at the offshore boundaries or within the model domain. This project is an ongoing collaboration with scientists from Naval research Laboratory-Stennis Space Center (NRL-SSC).

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Wave and Surf Forecasts, Data Assimilation

ROLE OF TIDAL FORCING IN DETERMINING THE INTERNAL WAVE SPECTRUM IN THE LITTORAL OCEAN

Jeffrey D. Paduan, Associate Professor
Leslie K. Rosenfeld, Associate Research Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The goal of this project is to develop a method, using a three-dimensional primitive equation model with realistic bathymetry, for simulating the internal wave energy produced along the coast by the action of tides.

SUMMARY: This project is investigating the nature of internal wave spectra in the littoral ocean environment using existing moored velocity time series and simulated coastal time series produced by a three-dimensional, primitive equation numerical model with realistic bathymetry forced by tidal-period sea level oscillations. The project has very specific goals that relate to the Littoral Internal Wave Initiative (LIWI), which seeks to quantify the physics of oceanic internal waves on the continental slope and shelf and to develop predictive models of their spectral characteristics. Studies are being conducted in the Monterey Bay region, where there are many near-bottom current meter records. Furthermore, the topography of the Monterey Submarine Canyon is known to produce very strong, bottom-intensified internal tides, which are the main subject of the numerical model simulations.

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CONFERENCE PRESENTATIONS:

Le, Ngoc Ly, Luong, P., Paduan, J.D., "A Variable-Resolution, 3-D Circulation Model for the Monterey Bay Region and Its Summer Simulations," American Geophysical Union Fall Meeting, San Francisco, CA, December 1998.

Paduan, J.D., "Coastal Oceanographic Processes," National Weather Service Marine Forecasters Workshop, Monterey, CA, June 1998.

Rosenfeld, L.K. and Paduan, J.D., "Numerical Simulations and Observations of the Internal Tide in a Submarine Canyon," scheduled to be presented at the 11th 'Aha Huliko'a Hawaiian Winter Workshop on Internal Wave Modeling, University of Hawaii, East West Center, Honolulu, HI, January 1999.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Ocean Currents, Tides, Internal Tides

SEASONDE MEASUREMENTS IN COPE-3

Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The goal of this project is to intercompare oceanographic field measurements from three types of high frequency radar instruments.

SUMMARY: This project sponsored the collection of SeaSonde High Frequency (HF) radar measurements from two sites off the U.S. Virginia coast as part of the third field phase of the Chesapeake Outfall Plume Experiment (COPE-3). The data collected consists of maps of surface ocean currents for a period of six weeks in October-November 1997. Similar data were collected by research colleagues using Ocean Surface Current Radar (OSCR) and Multi-frequency Coastal Radar (MCR) installations nearby.

PUBLICATIONS:

Vesecky, J., Teague, C., Fernandez, D., Paduan, J., Daida, J., Onstott, R., Laws, K., and Hansen, P., "Coastal Surface Currents With HF Radar," *Backscatter*, published by the Alliance for Marine Remote Sensing Association, pp. 12-20, August 1998.

Fernandez, D.M., Vesecky, J.F., Teague, C.C., Paduan, J.D., and Laws, K.E., "Ship Detection With High-Frequency Phased-Array and Direction-Finding Radar Systems," *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium,* Paper A08-11, Seattle, WA, July 1998.

Teague, C.C., Fernandez, D.M., Laws, K.E., Paduan, J.D., and Vesecky, J.F., "Comparison of Multi-frequency Phased-Array and Direction-Finding HF Radar Systems During COPE-3," *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium*, Paper A08-10, Seattle, WA, July 1998.

CONFERENCE PRESENTATIONS:

Paduan, J.D., Fernandez, D.M., Teague, C.C., Vesecky, J.F., and Laws, K., "Surface Currents Along the Continental Shelf South of Chesapeake Bay From HF Radar," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, February 1998.

Teague, C.C., Fernandez, D.M., Laws, K.E., Paduan, J.D., and Vesecky, J.F., "Multi-frequency Phased-Array and Direction-Finding HF Radar System Observations During COPE-3," American Geophysical Union Spring Meeting, Boston, MA, May 1998.

Vesecky, J.F., Teague, C.C., Paduan, J.D., Fernandez, D.M., Laws, K.E., Hallock, Z.R., and Meadows, L.A., "Observations of Air-Sea Dynamics by Multi-frequency HF Radar and Other Environmental Sensors Outside the Mouth of Chesapeake Bay During the COPE-3 Experiment of October-November 1997," American Geophysical Union Spring Meeting, Boston, MA, May 1998.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

DIURNAL TO SEASONAL VARIABILITY OF SURFACE OCEAN CURRENTS FROM HIGH FREQUENCY RADAR

Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The goals of this project are to describe the wind and tide forcing of the upper ocean currents around Monterey Bay and to develop optimized HF radar current algorithms.

SUMMARY: This research is drawing on data from a unique array of five HF radar systems around Monterey Bay: three CODAR-SeaSonde direction-finding systems and two multi-frequency phased array systems. The focus is on the 2-D surface currents and how they vary, both seasonally and daily, compared with measured winds and satellite AVHRR images. Data from the multi-frequency radar sites is being used to measure near-surface shear, which is difficult to do with in situ instrumentation. In addition, data from these systems, as well as simulations, are being used to examine the sensitivity of radar algorithms to varying current and wave conditions.

PUBLICATION:

Laws, K.E., Fernandez, D.M., Paduan, J.D., Teague, C.C., and Vesecky, J.F., "Simulation Studies of Errors in HF Radar Ocean Surface Current Measurements," *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium*, Paper A08-9, Seattle, WA, July 1998.

CONFERENCE PRESENTATIONS:

Delgado, R., Paduan, J.D., Teague, C.C., and Vesecky, J.F., "Mapping Wind Directions Over Monterey Bay With HF Radar," 45th Eastern Pacific Ocean Conference, Timberline, OR, September 1998.

Laws, K.E., Fernandez, D.M., Paduan, J.D., and Vesecky, J.F., "Simulation Studies of Errors in HF Radar Ocean Surface Current Measurements," 45th Eastern Pacific Ocean Conference, Timberline, OR, September 1998.

Lipphardt, B.L., Kirwan, A.D., Grosch, C.E., Lewis, J.D., and Paduan, J.D., "Mapping the Surface Velocity Field in Monterey Bay," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, February 1998.

Teague, C.C. and Laws, K.E., "HF Multi-frequency Ocean-Current Radar: MUSIC Direction Finding vs. Beam Formation," URSI Conference, Lisbon, Portugal, June 1998.

Teague, C.C., Vesecky, J.F., Paduan, J.D., Fernandez, D.M., and Onstott, R.G., "Multi-Frequency and Codar-Type HF Radar Observations of Surface Currents in Monterey Bay," American Geophysical Union Ocean Sciences Meeting San Diego, CA, February 1998.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

APPLICATION OF COASTAL OCEAN DYNAMICS RADARS FOR OBSERVATIONS OF NEAR-SURFACE CURRENTS IN THE SANTA BARBARA CHANNEL

Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: University of California-Santa Barbara

OBJECTIVE: The science objectives are to characterize the space and time variability of surface currents in and around the Santa Barbara Channel.

SUMMARY: The investigators involved in this project from the Naval Postgraduate School are collaborating with Professors Washburn and Gaines at the University of California, Santa Barbara on the deployment of shore-based HF radar systems along the coast west of Santa Barbara and moored and ship-based instruments in the waters offshore. The radar systems provide remotely-sensed maps of surface ocean currents to be used in the tracking of biologically important nutrients and larvae as well as potentially hazardous spilled materials.

CONFERENCE PRESENTATIONS:

Cook, M.S. and Paduan, J.D., "A MATLAB-Based System for Processing HF Radar Data," 45th Eastern Pacific Ocean Conference, Timberline, OR, September 1998.

Washburn, L., Emery, B.M., and Paduan, J.D., "Preliminary Results From an Array of HF Radars for Mapping Surface Currents in the Santa Barbara Channel," American Geophysical Union Fall Meeting, San Francisco, CA, December 1998.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

AN INNOVATIVE COASTAL-OCEAN OBSERVING NETWORK

Jeffrey D. Paduan, Associate Professor
Steve Ramp, Research Professor
Ching-Sang Chiu, Professor
Department of Oceanography
Sponsor: National Science Foundation and Office of Naval Research

OBJECTIVE: The objective of this project is to show that real-time data from HF radars and acoustic tomography can improve the performance of coastal circulation and biological productivity models.

SUMMARY: A concept demonstration is underway by a consortium of government, academic, and industrial partners to show how a diverse suite of modern, innovative ocean instrumentation can be successfully integrated into a functional, real-time ocean observation network. The plan calls for both creative application of well-established observational techniques and the development of new instrumentation and algorithms, which will be utilized in the network for the very first time. Moored, single-point time series observations, remotely-sensed data, ocean acoustic tomography, and two-dimensional

vector fields obtained from HF radars are being integrated into a cohesive picture of the coastal environment via a nested, high resolution numerical model. The sensor data and model output are being made available via Internet web pages for immediate application by coastal managers, defense analysts, emergency response teams, and commercial and recreational use.

CONFERENCE PRESENTATIONS:

Paduan, J.D., "Overview of the NOPP/ICON Project," National Ocean Partnership Program Initiation Workshop, Portland, OR, September 1998.

Paduan, J.D., Vesecky, J.F., Fernandez, D.M., Shulman, I., Chavez, F.P., Maffione, R.A., and Kindle, J.C., "An Innovative Coastal-Ocean Observing Network (ICON)," scheduled to be presented at the American Society of Limnology and Oceanography Conference, Santa Fe, NM, February, 1999.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

VARIABILITY OF THE SURFACE CIRCULATION AND TEMPERATURE IN THE ADRIATIC SEA

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main goal of this continuing project is to make effective drifter measurements of surface currents and surface temperature (SST) in the global Adriatic Sea in order to describe the spatial characteristics and the temporal variability of the surface circulation and the SST at inertial to seasonal scales. A related objective is to investigate some aspects of the response of the surface circulation and SST to atmospheric and boundary forcings. In particular, our goal is to study the characteristics of the wind-driven currents in relation to the surface wind forcing, obtained from wind measurements and from atmospheric model products. Another aim is to explore the role of eddies (versus mean currents) in transporting momentum and heat.

SUMMARY: A total of 63 modified-CODE drifters and 3 GDP/MINIMET drifters were successfully deployed between 22 August and 22 September 1998 by colleagues of the Osservatorio Geofisico Sperimentale, Trieste (OGS) and other Italian and Croatian institutes. In-situ wind observations were made following the release of the GDP/MINIMET drifters for wind calibration purposes.

The drifter data were downloaded from Service Argos on a daily basis. After some pre-processing and data reduction, graphical representations of the drifter statistics, of the drifter trajectories and the temperature time series, etc., were produced and updated every day in a dedicated world wide web page (http://www.oc.nps.navy.mil/~drifter). The data were also quality controlled, reduced and edited for obvious outliers. They were then added to the drifter database. All the edited drifter data were low-pass filtered (36 hour cut-off) and uniformly interpolated at 6-hour intervals. Drifter velocities were estimated by finite differencing the position data.

The drifter data were used to explore the variability of the surface circulation in the Adriatic and Ionian Seas. Besides the mesoscale fluctuations, important variations of the mean circulation at seasonal (and even interannual) scales were observed, especially in the northern Ionian and southern Adriatic. Satellite thermal images of the Adriatic were processed at the Satellite Oceanography Laboratory of the University of Hawaii. The processing included registration, navigation, calculation of SST and cloud masking. The SST maps were made available on the internet (http://satftp.soest.hawaii.edu/adriatic/Adriatic/) and on a CD-ROM that was distributed to the oceanographic community.

A statistical comparison between contemporaneous SST data from drifters and from satellite images provided satisfactory results. The satellite SST images were analyzed to provide image composites over 3-day, weekly and monthly periods. A qualitative description of the surface mesoscale structures in the Adriatic and of their associated temporal variability was

done by superimposing drifter trajectory segments on the satellite images. Most of the time, there is a remarkable agreement between the drifter motions and the structure and evolution of the SST features.

The entire drifter data set (November 1994 through December 1998) and the in-situ wind observations will be interpreted and results will be published as part of the continuation of this project into 1999.

PUBLICATIONS:

Kovacevic, V., Gacic, M., and Poulain, P.-M., "Subtidal Water Flow Across the Strait of Otranto During Winter, Summer and Autumn Periods," *Rapports de la Commission Internationale de la Mer Mediterranee*, 35, pp. 156-157, 1998.

Poulain, P.-M., "Lagrangian Measurements of Surface Circulation in the Adriatic and Ionian Seas Between November 1994 and March 1997," *Rapports de la Commission Internationale de la Mer Mediterranee*, 35, pp. 190-191, 1998.

Poulain, P.-M. and Zanasca, P., "Drifter and Float Observations in the Adriatic Sea (1994-1996) - Data Report," *SACLANTCEN Memorandum*, SM-340, SACLANT Undersea Research Centre, La Spezia, Italy, 1998.

Poulain, P.-M., Nacini, E., Pouliquen, S., and Flament, P., "Adriatic Sea - Sea Surface Temperature Images From the NOAA Advanced Very High Resolution Radiometer: 9 May to 22 October, 1995," *CD-ROM, Institut francais de recherche pour l'exploitation de la mer,* Plouzane, France, 1998.

Poulain, P.-M., "Drifter Observations of Surface Circulation in the Adriatic Sea," *Journal of Marine Systems*, 1999, in press.

Kovacevic, V., Gacic, M., and Poulain, P.-M., "Eulerian Current Measurements in the Strait of Otranto and in the Southern Adriatic," *Journal of Marine Systems*, 1999, in press.

Poulain, P.-M. and Zanasca, P., "Lagrangian Measurements of Surface Currents in the Northern and Central Adriatic Sea," *Ecosystems Research Report*, The Adriatic Sea, EU/Environment Series, Brussels, Belgium, 1999, in press.

CONFERENCE PRESENTATIONS:

Kovacevic, V., Gacic, M., and Poulain, P.-M., "Subtidal Water Flow Across the Strait of Otranto During Winter, Summer and Autumn Periods," 35th Congress of the Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranee, Dubrovnik, Croatia, 1-5 June 1998.

Poulain, P.-M., Gacic, M., Sellschopp, J., and Niiler, P., "Recent Lagrangian Measurements of Surface Circulation in the Adriatic and Ionian Seas," American Geophysical Union Ocean Sciences Meeting, San Diego, CA, 9-13 February 1998.

Poulain, P.-M., "Lagrangian Measurements of Surface Circulation in the Adriatic and Ionian Seas Between November 1994 and March 1997," 35th Congress of the Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranee, Dubrovnik, Croatia, 1-5 June 1998.

Poulain, P.-M., "Twenty Years of Lagrangian Measurements in the Adriatic Sea: A Review," International Workshop on the Adriatic Sea Oceanography, Trieste, Italy, 21-25 September 1998.

Poulain, P.-M. and Schlining, B., "Variability of the Surface Circulation in the Ionian Sea as Deduced From Drifter Trajectories," American Geophysical Union Fall Meeting, San Francisco, CA, 6-10 December 1998.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Marginal Seas and Straits, Circulation

ADRIATIC SEA CIRCULATION: TIDAL AND WIND-DRIVEN CURRENTS IN CROATIAN COASTAL WATERS

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to study the variability of the currents and water mass properties in the Adriatic Sea at tidal/inertial to seasonal scales using a variety of Lagrangian, Eulerian and satellite data sets. First, surface drifters data and satellite thermal/color imagery between August 1997 and December 1998 are used to study the circulation and related surface thermal/pigment structures in the entire Adriatic basin. Second, studies are conducted to compare modeled and observed near-surface drifter trajectories with the goal of improving future drifter deployment strategies and of assessing model capabilities. Third, effective measurements of currents and water mass properties are made in Croatian coastal waters in order to study the dynamics of selected key areas where tidal and wind forcings are crucial.

SUMMARY: The first task of this project was completed in 1998. Satellite images were obtained and processed to create surface maps of temperature and pigment concentration in the Adriatic over a period of a year. Temperature and pigment are good tracers that are advected by the mean and mesoscale circulation features. The combination of the satellite images with the drifter displacement data provided a unique description of important mesoscale phenomena, such as the Western Adriatic Current and its instabilities, gyre circulation patterns in the southern and northern Adriatic, etc.

The intercomparison study between Lagrangian data and ocean circulation model results will be performed in 1999. Unfortunately the sea-going operations planned in the Croatian coastal waters were cancelled due to political/military problems in the Balkans.

CONFERENCE PRESENTATIONS:

Mauri, E., Poulain, P.-M., and Gacic, M., "Surface Circulation of the Adriatic Sea From Satellite and Lagrangian Data: Preliminary Results," International Workshop on the Adriatic Sea Oceanography, Trieste, Italy, 21-25 September 1998.

Mauri, E. and Poulain, P.-M., "Adriatic Sea Circulation as Derived From Seawifs, AVHRR and Drifter Data," American Geophysical Union Fall Meeting, San Francisco, CA, 6-10 December 1998.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Circulation, Lagrangian Drifters, Satellite Imagery, Numerical Models

LAGRANGIAN MEASUREMENTS IN ICELANDIC WATERS

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: North Atlantic Treaty Organization

OBJECTIVE: The main objective of this continuing project is to analyze drifter observations in the Icelandic waters collected by the SACLANT Undersea Research Centre, La Spezia, Italy in 1991-1995 and by the Marine Research Institute (MRI) of Reykjavik, Iceland (1995-1998) in order to define the main pathways of the surface circulation and describe their eddy and seasonal variabilities. A related goal is to use and combine satellite thermal imagery with the in-situ drifter measurements to provide the most complete description of the mesoscale variability.

SUMMARY: The drifter data sets up to the end of 1997 were processed to create low-passed, uniformly sampled trajectories. Seasonal maps of mean currents and eddy kinetic energy were produced. The Lagrangian nature of the drifters was exploited to estimate decorrelation time and length scales and eddy diffusivities in selected regions. This project will continue into 1999 with the final processing and data interpretation (statistical analyses).

PUBLICATION:

Perkins, H., Hopkins, T.S., Malmberg, S.-A., Poulain, P.-M., and Warn-Varnas, A., "Oceanographic Conditions East of Iceland," *Journal of Geophysical Research*, 103(C10), pp. 21531-21542, 1998.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Upper Ocean Circulation, Lagrangian Drifters, Icelandic Coastal Waters

LAGRANGIAN DATA ANALYSIS IN MESOSCALE PREDICTION STUDIES

Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is the development and application of new methods of investigation for the use of Lagrangian data in mesoscale problems. Particular focus is given to the use of Lagrangian data in coastal regions and semi-enclosed basins. Two specific studies are proposed using surface drifter in the Adriatic Sea and Sicilian Channel: (a) the investigation and prediction of mesoscale processes in the two regions and (b) the estimation of Lagrangian errors which can be important for the intercomparison between data and model results.

SUMMARY: Drifter data between December 1994 and March 1996 were used to assess some characteristics of the mesoscale motion in the Adriatic Sea, addressing questions such as how strong is the topographical constraint, and to which extent the motion is directly driven-driven or caused by instabilities. In particular, the surface transport properties were studied for particles entering the basin through its southern entrance (Strait of Otranto). The use of a simple transport model (advection-diffusion) was investigated. Residence times in the basin were also estimated.

This project will continue into 1999 with the calculation of transport properties in the Adriatic Sea and in the Sicilian Channel using Lagrangian data obtained between November 1994 and December 1998. An assessment of the instrumental error of the surface drifter measurements and of the Lagrangian statistical sampling errors will be performed.

CONFERENCE PRESENTATIONS:

Griffa, A., Poulain, P.-M., and Zambianchi, E., "Validazione di modelli per variabilita' climatica usando dati in situ: il caso di dati Lagrangiani, vantaggi e difficolta," Seasonal, Interannual and Decadal Variability of the Atmosphere, Ocean and Related Marine Ecosystems (SINAPSI) Workshop, Rome, Italy, 6-8 April 1998.

Griffa, A., Poulain, P.-M., and Zambianchi, E., "Estimates of Transport Parameters From Lagrangian Data in the Adriatic Sea," International Workshop on the Adriatic Sea Oceanography, Trieste, Italy, 21-25 September 1998.

Bauer, S., Falco, P., Griffa, A., Poulain, P.-M., and Zambianchi, E., "Stima dei parametri del trasporto nel Mare Adriatico a partire da dati lagrangiani," XII National Congress of Associazione Italiana di Oceanologia e Limnologia, Portonovo (Ancona), Italy, 28-30 September 1998.

Falco, P., Griffa, A., Poulain, P.-M., and Zambianchi, E., "Transport Processes in the Adriatic Sea Estimated From Lagrangian Data," 1st National Congress on Marine Sciences – Diversita' e Cambiamento, COnsorzio Nazionale Interuniversitario per le Scienze del Mare (CONISMA), Ischia, Italy, 11-14 November 1998.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Oceanic Transports and Dispersion, Lagrangian Drifters, Mesoscale Motion

ADVANCED ANALYSIS AND SYNTHESIS OF THE EASTERN BOUNDARY CURRENT ADVANCED RESEARCH INITIATIVE (ARI) DATA SET

Steven R. Ramp, Research Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: There were two objectives this year under ONR funding, one wrap-up and one new start. Task 1 was to complete the analysis and publication of the moored array data from the ONR EBC/ARI, conducted off central California during 1992-96. Specifically, the PI is a co-author on two papers written for the *Journal of Geophysical Research*. The second objective of the grant was to continue working with Professor Ching-Sang Chiu (also of NPS) planning a joint physical oceanography/environmental acoustics experiment to be conducted in one of China's neighboring seas during the 2000-2001 time period. Interactions will continue with scientists from the PRC and several other nations, most notably Singapore and Taiwan, to establish the when, where, and how of this upcoming international program.

SUMMARY: The continental slope region off central California was found to be an eddy generation, rather than an eddy dissipation region. Over the slope, the poleward-flowing California Undercurrent (CUC) was most prevalent, interspersed with meanders and eddies of both signs. Farther offshore, fewer eddies were observed, all deep, warm anticyclones. The eddy kinetic energy peaked near 60 days over the slope, and near 120-180 days farther offshore. Using ancillary data from other EBC/ARI investigators and the World Ocean Circulation Experiment (WOCE), the origin of one warm anticyclone offshore was traced back to the CUC [Chereskin, et al., 1998]. It seems clear now that eddies in the California Current represent a mechanism for transporting materials from the coast to the central North Pacific.

Singapore and Taiwan have now signed on to participate in the China Seas field program. The addition of these nations to the observational effort will have a significant impact on the magnitude of the Navy's plans. Singapore will make much more complete ambient noise measurements than would otherwise have been made. Taiwan will bring a second modern research vessel, a second SEASOAR instrument, and four ATLAS buoys to the physical oceanography program.

PUBLICATIONS:

Ramp, S.R. and Abbott, C.L., "The Vertical Structure of Currents Over the Continental Shelf Off Point Sur, CA, During Spring 1990," *Deep-Sea Research II*, 45, 1443-1470, 1998.

Noble, M. and Ramp, S.R., "Moored Observations of the Structure and Variability of the California Undercurrent Off the Farallon Islands, CA," *Deep-Sea Research II,* 1999, in press.

Chereskin, T.K., Morris, M.Y., Niiler, P.P., Kosro, P.M., Smith, R.L., Ramp, S.R., Collins, C.A., and Musgrave, D. L., "Spatial and Temporal Characteristics of the Mesoscale Circulation of the California Current From Eddy-Resolving Moored Measurements," *Journal of Geophysical Research*, 1998, submitted.

Kosro, P., Ramp, S.R., and Smith, R.L., "Currents Over the Continental Slope Off Point Arena, CA.," *Journal of Geophysical Research*, 1998, in preparation.

CONFERENCE PRESENTATION:

Ramp, S.R. and Bluth, R.T., "Plans and Progress at the Naval Postgratuate School's Remotely Piloted Aircraft Center," Eastern Pacific Oceanographic Conference, Timberline Lodge, OR, 23-26 September 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Other (Modeling and Prediction)

KEYWORDS: California Current, Coastal Oceanography, Environmental Acoustics, South China Sea

INTERNAL WAVES AND TURBULENCE IN MONTEREY SUBMARINE CANYON

Leslie Rosenfeld, Research Associate Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: To determine the finescale shape and level of the vertical wavenumber spectra for vertical displacement and horizontal velocity as compared with the open ocean Garrett-Munk model; to determine the spatial scale and heterogeneity of the internal wave field as a function of vertical, along- and across-canyon position; and to determine the anisotropy of the internal wave field to evaluate where the dominant semidiurnal tide is best described as propagating, and where as standing. This project will continue for another year.

SUMMARY: The first year of this project (FY97) focused on preparation for, and execution of, the field experiment, which was executed in cooperation with Eric Kunze (the co-PI on this project) and Mike Gregg of University of Washington, who are funded by ONR for a closely related study. Using MBARI's R/V *Point Lobos*, two near-bottom upward-looking 300 kHz acoustic doppler current profilers (ADCPs) were deployed in the Monterey Canyon on 4 August 1997 and recovered on September 9. A 14-day cruise (8-21 August) was completed on the R/V *Point Sur*, during which conductivity, temperature, depth (CTD), vessel-mounted ADCP, microstructure and dissipation measurements were made. During the second year of the project, CTD, ADCP, and other ancillary, data were processed and analyzed, and interpretation was begun. Kinetic energy levels were found to be greatly elevated above that predicted by the G-M model. A high degree of nonlinearity was found as evidenced by energetic overtides and the presence of upcanyon-propagating internal bores. The vertical structure of the semidiurnal internal tide was found to be highly variable, even over the short duration of the cruise.

PUBLICATION:

Petruncio, E.T., Rosenfeld, L.K., and Paduan, J.D., "Observations of the Internal Tide in Monterey Canyon," *Journal of Physical Oceanography*, 28: 1873-1903, 1998.

CONFERENCE PRESENTATIONS:

Rosenfeld, L.K. and Kunze, E., "Internal Waves in Monterey Submarine Canyon: Preliminary Results," American Geophysical Union, 1998.

Rosenfeld, L.K. and Kunze, E., "Internal Waves in Monterey Canyon," Coastal Ocean Processes, Woods Hole, MA, 27-30 September 1998.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Internal Waves, Submarine Canyons, Turbulence

EL NIÑO OFFSHORE

Leslie Rosenfeld, Research Associate Professor
Department of Oceanography
Sponsor: U.S. Geological Survey

OBJECTIVE: To determine the sediment budget for Monterey Bay.

SUMMARY: A surface mooring and a trawl-resistant bottom mount were deployed on the continental shelf north of Monterey Bay from April-August 1998. The former supported temperature, salinity, and current measuring devices, a sediment trap, and a pressure sensor. The latter supported an acoustic doppler current profiler. These measurements extended an existing project to study the sediment budget for Monterey Bay, such that 2.5 year-long time series are now available to assess changes in shelf circulation and water properties related to the 1997/1998 El Niño event.

DoD TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Sediment Transport, Monterey Bay, Nearshore Currents

APPLICATION OF PARALLEL OCEAN AND CLIMATE MODELS TO DECADE/CENTURY PREDICTION

Albert J. Semtner, Professor
Robin Tokmakian, Research Assistant Professor
Wieslaw Maslowski, Research Assistant Professor
Julie McClean, Research Assistant Professor
Yuxia Zhang, Research Assistant Professor
Department of Oceanography
Sponsor: U.S. Department of Energy

OBJECTIVE: To use ocean, atmosphere, and ice models developed during earlier research under the DoE CHAMMP Program in order to simulate realistic climate states using advanced parallel computers. To understand the physical processes in the ocean that affect ocean predictability and climate variations and change.

SUMMARY: This five-year project has just begun. It uses various advanced models to understand the variability of ocean and ocean-ice circulation at relatively high resolution. The NPS group collaborates with large climate modeling efforts at Los Alamos National Laboratory and at the National Center for Atmospheric Research in order to be at the forefront in simulation.

PUBLICATIONS:

Maltrud, M.E., Smith, R.D., Semtner, A.J., and Malone, R.C., "Global Eddy-Resolving Ocean Simulations Driven by 1985-94 Atmospheric Fields," *Journal of Geophysical Research*, 103, pp., 30825-30854, 1998.

Semtner, A.J., "Ocean and Climate Modeling on Advanced Parallel Computers: Progress and Prospects," *Communications of the Association for Computing Machinery*, 1998, in press.

Semtner, A.J. and Zhang, Y., "Antarctic Currents in High Resolution Ocean and Climate Models," *Annales Geophysicae, Book of Abstracts, Part II*, European Geophysical Union, Katlenburg-Lindau, Germany, p. 591, 1998.

Zhang, Y. and Semtner, A.J., "Ocean-Ice Interaction Within the Weddell and Cosmonaut Seas From High-Resolution Models," *Annales Geophysicae, Book of Abstracts, Part II*, European Geophysical Union, Katlenburg-Lindau, Germany, p. 592, 1998.

CONFERENCE PRESENTATIONS:

Semtner, A.J., "The DoE Parallel Climate Model," DoE-Sponsored Workshop on Strategic Simulation for the Jasons, La Jolla, CA, 1-3 July 1998.

Semtner, A.J., "Modeling Decadal to Century Climate Change on Parallel Computers," Science Team Meeting for the DoE Climate Change Prediction Program, Phoenix, AZ, 12-13 October 1998.

Semtner, A.J., "Ocean Climate Modeling on Advanced Parallel Computers: Progress and Prospects," Supercomputing '98 - Tenth Anniversary Conference, Orlando, FL, 17-19 October 1998.

OTHER:

Semtner, A.J., "Environmental Research and Ocean Prediction at the Naval Postgraduate School," Meeting of Monterey Scientists with Congressman Sam Farr, Moss Landing, CA, 14 January 1998.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction, Parallel Computing

SIMULATIONS AND RECONSTRUCTIONS OF GLOBAL OCEAN CIRCULATION WITH WELL-RESOLVED EDDIES FOR THE WOCE OBSERVATIONAL PERIOD

Albert J. Semtner, Professor
Department of Oceanography
Sponsors: National Science Foundation and Naval Postgraduate School

OBJECTIVE: The goal is to further improve on the realism of numerical models of global three-dimensional ocean circulation with important currents and eddies resolved and to conduct simulations using the best available atmospheric forcing. The multi-year project runs into the year 2000.

SUMMARY: A model had been developed with 1/4 x 2/5 deg lat/lon grid and 20 vertical levels, with proper representation of coastlines and depths. Last year, the most recent five years of operational winds and heat and moisture fluxes from the European Center for Medium-range Weather Forecasts were prepared as forcing. Robin Tokmakian simulated conditions of 1994-98, starting from earlier 1979-93 ECMWF reanalysis-forced calculations. A massive amount of model output was compared with both in-situ and satellite observations and found to be in excellent agreement. These recent results are being prepared for publication.

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Craig, A.P., Bullister, J.L., Harrison, D.E., Chervin, R.M., and Semtner, A.J., "A Comparison of Temperature, Salinity, and Chloro-Fluorocarbon Observations With Results From a One-Degree Three-Dimensional Global Ocean Model," *Journal of Geophysical Research*, 103, pp. 1099-1120, 1998.

Chervin, R.M., Craig, A.P., and Semtner, A.J., "Meridional Heat Transport Variability From a Global Eddy-Resolving Ocean Model," *Assessing Climate Change*, W. Howe and A. Henderson-Sellers, (eds.), Gordon and Breach Science Publishers, Roseville, Australia, 1998, in press.

Semtner, A.J., "Very High-Resolution Estimates of Global Ocean Circulation, Suitable for Carbon-Cycle Modeling," *Proceeding of the Snowmass Global Change Institute on the Global Carbon Cycle*, T. Wigley, (ed.), Office of Interdisciplinary Earth Studies, Boulder, CO, 1998, in press.

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Semtner, A.J., "Modeling Southern Ocean Circulation on Parallel Computers," Climate System Modeling Workshop and Advisory Board Meeting, Breckenridge, CO, 15-18 July.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction

UNDERSTANDING SEASONAL TO DECADAL CLIMATE CHANGES THROUGH THE COMBINED USE OF IMPROVED MODELS AND SATELLITE DATA

Albert J. Semtner, Professor
Robin Tokmakian, Research Assistant Professor
Julie McClean, Research Assistant Professor
Department of Oceanography
Sponsor: National Aeronautics and Space Administration-Jet Propulsion Laboratory

OBJECTIVE: The goal is to use improved models and satellite date to understand climate changes on seasonal, interannual, decadal, and interdecadal time scales.

SUMMARY: We have been using high-resolution global ocean models and satellite data to define a set of indices that can be used to identify seasonal, interannual, and decadal changes in the climate of the World Ocean. The global models have 1/4-degree out to 1/10-degree grid size forced with reanalyzed wind stress and heat/freshwater fluxes. The model output is being compared to the TOPEX height fields and other satellite data to investigate variations in the thermohaline and wind-driven ocean circulation as they relate to global climate. This was the second of three project years.

PUBLICATIONS:

Tokmakian, R., McClean, J.L., and Semtner, A.J., "Understanding Seasonal to Decadal Climate Changes Using Models and Satellite Data," *AVISO Altimetry Newsletter*, 6, pp. 113-115, 1998.

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CONFERENCE PRESENTATIONS:

Semtner, A.J. and Zhang, Y., "Antarctic Currents in High-Resolution Ocean and Climate Simulations," Annual Symposium of the European Geophysical Society, Nice, France, 20-24 April 1998.

Tokmakian, R., McClean, J., Semtner, A., and Braccio, P., "Surface Detectable Ocean Climate Signals: Satellite Data and an Ocean Model Simulation," TOPEX/POSEIDON Science Team Meeting, Keystone, CO, 13-15 October 1998.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction

DEVELOPMENT OF A NEW ARCTIC ICE-OCEAN PREDICTION SYSTEM (PIPS 3.0)

Albert J. Semtner, Professor
Wieslaw Maslowski, Assistant Research Professor
Yuxia Zhang, Assistant Research Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: To modernize the existing ice prediction system used in operational forecast of the Arctic by the U.S. Navy.

SUMMARY: A workshop was held in July of 1998 to begin the process of bringing new physics modules by various ONR-supported investigators into a modern NPS ice-ocean model. This model is run at high resolution on highly parallel computers of the type to be at Fleet Numerical Meteorology and Oceanography Center in the future. Since the workshop, a new 9-km horizontal grid and 40-km ocean model have been constructed. The ice model is being readied at the same horizontal grid spacing. A Website has been set up to allow communication with remote investigators. A GS-12 programmer/scientist with expertise in earlier ice modeling is being hired to expedite integration of all the components.

PUBLICATIONS:

Maslowski, W., McClean, J., Newton, R., Schlosser, P., Zhang, Y., Semtner, A.J., and Martinson, D.G., "Modeling Interannual Variability of the Arctic Ocean and Sea Ice Circulation," *EOS Transactions*, American Geophysical Union, Washington, DC, December 1998.

Murley, S.P., Maslowski, W., Bourke, R.H., Zhang, Y., and Semtner, A., "Variability of Freshwater Export Through Fram and Davis Straits From a High-Resolution Model," *EOS Transactions*, American Geophysical Union, Washington, DC, December 1998.

CONFERENCE PRESENTATION:

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THESIS DIRECTED:

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DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction

MIXED LAYER TURBULENCE MEASUREMENTS DURING THE ANZONE WINTER FLUX EXPERIMENT: ANZFLUX

Timothy P. Stanton, Associate Research Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVES: The objectives of this research are to identify and model physical mechanisms responsible for maintaining anomalously thin winter ice cover over the central Weddell Sea. As large scale, winter-long polynias intermittently form in this area, the potential exists for massive ocean/atmosphere heat fluxes which can significantly effect the global heat budget and bottom water formation.

SUMMARY: During the participation in the ANZFLUX experiment, deployed from the icebreaker N. B. Palmer during July and August 1994, two, one week ice camps were established approximately 500m from the ship on O(30 cm) ice to make direct heat, salt and momentum flux measurements in the ocean mixed layer. Analysis has been completed on the continuous profiling microstructure probe, a turbulence-resolving Broad Band Acoustic Doppler Current profiler, and three near-surface *in situ* temperature, salinity and three component velocity instrument clusters. These observations show that strong turbulent coupling between the deep pycnocline and the surface ice occurs during the very high wind stress events which dominated the weather at the measurement site. High mixed layer heat fluxes during these events are further enhanced by dramatic shallowing of the pycnocline due to the presence of eddy features in the Central Weddell Sea. The continuous mixed layer and upper pycnocline profile measurements resolved the evolving mixed layer thermohaline structure, turbulent dissipation rates and very small vertical gradients of temperature and salinity, allowing heat fluxes and pycnocline diffusivity timeseries to be estimated.

An analysis of the pycnocline fluxes estimated from the field observations has been completed in collaboration with investigators at Oregon State University, and submitted to the *Journal of Geophysical Research*. A paper is in progress describing the turbulent structure of the sub-ice mixed layer and unique comparisons of acoustic doppler measurements of boundary layer turbulence using conventional geometry acoustic doppler profilers demonstrate a new application of acoustic doppler current profilers. A collaborative paper with Miles McPhee on a simple mixed layer flux parameterization of mixed layer turbulence based on surface stress and observed T/S profiles is also in progress.

PUBLICATIONS:

Stanton, T.P., Padman, L., and Robertson, R.A., "Heat Fluxes Through the Permanent Pycnocline in the Eastern Weddell Sea," *Journal of Geophysical Research*, 1998, submitted.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Mixed Layer, Antarctic Ocean Fluxes, Mixed Layer Dynamics

SPECTRAL WAVE DECAY DUE TO BOTTOM FRICTION ON THE INNER SHELF

Timothy P. Stanton, Research Associate Professor
Edward B. Thornton, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: The objectives of this research are to directly measure wave dissipation as surface gravity waves propagate across continental shelves. Observations of dissipation in the thin oscillatory bottom boundary layer, bottom morphology and low frequency currents will be used to develop a spectral wave model of dissipation for use in shelf wave models.

SUMMARY: During this second year of the 5-year Defense Research Initiative, a prototype very high resolution doppler acoustic doppler profiler (the BCDV) was deployed for a 6-week period at Duck, NC during the SANDYDUCK experiment. This instrument was deployed along with a scanning X/Y altimeter to measure profiles of three component velocity vectors over a 60cm range above the bed, while simultaneously measuring the local fine-scale morphology. The instruments were mounted on a moveable sled, allowing conditions representative of the inner shelf to be measured over a wide range of wave forcing.

Analysis techniques have been developed to estimate profiles of Reynolds stresses, shear and hence shear production of TKE, and strain-based dissipation estimates. A paper describing these techniques and results from SANDYDUCK is in progress. Techniques are also nearing completion for reducing the scanned altimeter data into corrected morphology maps. A design for a high resolution BCDV and deployment infrastructure has also been completed in preparation for the main Shoaling Waves experiment in the fall of 1999.

PATENT:

Turbulence-Resolving Coherent Acoustic Sediment Flux Probe, U.S. Navy application number 77525.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Wave Dissipation, Shoaling Waves, Bottom Boundary Layers

UPPER OCEAN EFFECTS ON THE SURFACE HEAT BUDGET OF THE ARCTIC

Timothy P. Stanton, Associate Research Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVES: The objectives of this research are to measure the mixed layer and upper ocean heat content and heat fluxes over a one year period in the central Arctic Ocean. This work is a component of the multidisciplinary SHEBA program which has the objectives of improving parameterizations of the coupled atmosphere-ice-ocean system in the Arctic to improve the predictive capabilities of Global Climate Models. A shorter process study focused on the role of ice keels in the surface heat balance.

SUMMARY: Between October 1997 and October 1998 the SHEBA ice camp was deployed in the Central Beaufort Sea. An automated conductivity, temperature, depth (CTD) and microstructure profiler measured turbulent fluxes and the temperature/salinity structure of the upper ocean for the year period as the ice camp drifted in response to surface wind forcing. The microstructure package was designed and built at NPS, and tested in September 1997 in Puget Sound.

Data from the daily profile timeseries were downloaded via a satellite link allowing checks of the extremely delicate micro-temperature sensors to be monitored, and the data to be analyzed while the measurements were in progress. Analysis of the upper ocean salinity structure has revealed evidence of very significant ice melting in the last few seasons, and a paper describing this result has been published in *Geophysical Research Letter*. A conference presentation has also been prepared discussing the strong regional effect of warm underlying water in the mixed layer heat fluxes.

A unique, self contained portable ocean heat, salt and momentum flux instrument was completed and deployed in an ice keel study in March 1998. This self-contained ocean flux probe allows mixed layer momentum, heat and salt fluxes to be measured for periods of up to two months. An analysis of three simultaneous ocean mixed layer flux sites near differing ice topographies is in progress.

PUBLICATION:

McPhee, M.G., Stanton, T.P., Morison, J.H., and Martinson, D.G., "Freshening of the Upper Ocean in the Central Arctic: Is Perennial Sea Ice Disappearing?" *Geophysical Research Letter*, 25, pp. 1729- 1732, 1998.

CONFERENCE PRESENTATION:

Stanton, T.P., "Ocean Heat Fluxes and Pycnocline Entrainment During SHEBA," 13th Conference on Boundary Layers and Turbulence, American Meteorology Society Meeting, Dallas, TX, 10-15 January 1999.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Ocean Mixed Layer, Polar Oceans, Mixed Layer Dynamics.

NEARSHORE WAVE AND SEDIMENT PROCESSES

Edward B. Thornton, Distinguished Professor
Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: To predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the nearshore given the offshore wave conditions.

SUMMARY: Data acquired during the SandyDuck nearshore experiment are being analyzed compared with models developed under this program and in collaboration with other groups. During SandyDuck, the vertical distributions throughout the water column of 3-component mean, wave-induced and turbulent velocities, bubbles, sediment concentrations were measured using an instrumented sled to study. The 3-component velocity field was measured every 5 cm over the bottom 1 m with a downward looking 1.2 MHZ bistatic coherent acoustic Doppler velocimeter (1.6 cm resolution at 48 Hz) and in the upper water column with a 300 KHz upward looking coherent bistatic acoustic doppler velocimeter every 8 cm (8 cm resolution at 48 Hz). In addition, the vertical distribution of the horizontal velocities were measured with an array of 8 electromagnetic current meters. A 2 m cross-shore array of optical backscatter instruments measured the coherence length scale and advection. The small-scale morphology, which acts as hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, was measured from the sled with newly developed, in-house, x-y scanning altimeter, and with an array of 7 sonic altimeters mounted on the back of the CRAB. The primary mechanism for changes in moment flux which drives the nearshore dynamics is due to the dissipation of breaking waves, the processes of which are only poorly understood. To improve the understanding of breaking waves, the dissipation associated with bubble injection and depth of bubble penetration were measured with the two acoustic systems (1.2 MHZ looking down and 300KHz looking up) and with a 3 m vertical array of 8 conductivity cells. An important component of the cross-shore sediment flux is due to the cross-shore mean flow (undertow), which is forced by wave set-up/down; the set-up was measured with an array of 8 pressure sensors. Undertow is an integral measure of the turbulent Reynold's stresses and wave radiation stresses and acts as a check for the detailed velocity measurements.

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Thornton, E.B., (ed.), *Proceeding of Coastal Dynamics '97, American Society of Civil Engineering*, 1070 pp., 1998.

Garcez Faria, A.F.G., Thornton, E.B., Lippmann, T.C., and Stanton, T.P., "Undertow Over a Barred Beach," *Journal of Geophysical Research*, 1998, submitted.

Lippmann, T. and Thornton, E.B., "The Spatial Distribution of Wave Rollers and Turbulent Kinetic Energy on a Barred Beach," *Journal of Geophysical Research*, 1998, accepted.

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Thornton, E.B., Huck, M.P., and Stanton, T.P., "Vertical and Horizontal Length Scales of Suspended Sediments in the Nearshore," American Geophysical Union Fall Meeting, San Francisco, CA, 6-10 December 1998.

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THESIS DIRECTED:

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DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: NearShore, Waves, Surf

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TEN YEARS OF HYDROGRAPHIC VARIABILITY OFF THE CENTRAL CALIFORNIA COAST DURING THE UPWELLING SEASON

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Analysis of mean conditions and variability during the upwelling season off central California was performed on data sets of buoy and shoreline surface measurements and conductivity, temperature, and depth (CTD) data from ten annual National Marine Fisheries Service (NMFS) surveys (1987-1996). Climatologies of the surface conditions (alongshore wind, sea surface temperature (SST), sea surface salinity (SSS)) revealed that the height of the upwelling season occurred during May and June. Variability in the surface conditions was high both inter-annually and inter-seasonally with maximum equatorward wind, lowest SST, and highest SSS during the months of May and June. Ten-year climatologies of hydrographic conditions from CTD data (depth and salinity on density anomaly surfaces, and temperature, salinity, density at discrete depths) indicated complex circulation patterns and water mass properties. The nearshore region contained relatively dense, upwelled water and isopycnal gradients conformed to local bathymetry. A robust upwelling filament off Pt. Reyes and three anticyclonic eddy-like features west of the shelf break appeared in the climatologies. Empirical orthogonal function (EOF) analysis of the subsurface variability confirmed the presence of the prominent features that appeared in the climatologies. The geophysical signals of the first three EOF-amplitude pairs represent a cross-shore mean upwelling pattern, an alongshore pattern caused by spatial variations in wind and gradients of water mass characteristics, and a filament-eddy resolving pattern, respectively.

KEYWORDS: Upwelling, Filaments, Eddies, Mesoscale Circulation, Empirical Orthogonal Functions

DoD KEY TECHNOLOGY AREA: Other (Coastal and Fisheries Oceanography)

OCEANOGRAPHY OBSERVED DIRECTIONAL SPECTRA OF SHOALING AND BREAKING WAVES

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The evolution of the frequency-directional wave spectrum, $E(f, 0)$, across the inner continental shelf and beach was examined with measurements collected at the U.S. Army Corps of Engineer's Field Research Facility during the recent SandyDuck experiment. Arrays of bottom pressure sensors were deployed on the shelf in 20 m depth and on the beach in depths ranging from 2 - 5 m. These arrays were complemented by a directional wave buoy in 20 m depth and an array of pressure sensors in 8 m depth maintained by the U.S. Army Corps of Engineers. A preliminary analysis of these data is presented here focused on four case studies that illustrate the observed wave shoaling evolution in both non-breaking and breaking conditions. Estimates of $E(f,0)$ extracted from array cross-spectra at six cross-shore locations are compared to predictions of linear refraction theory. The present observations support conclusions from previous studies that the cross-shore evolution of dominant wave propagation direction is well described by linear refraction theory. Observations of harmonic peak development at directions aligned with the dominant waves are consistent with theoretical wave-wave interaction rules and previous observations. In both non-breaking and breaking conditions, the observed $E(f, 0)$ are directionally broader than predicted. In contrast to previous observations on a barred beach, the present observations on a planar beach do not show a dramatic broadening of directional wave spectra in the surf zone.

DoD KEY TECHNOLOGY AREA: Other (Environmental Prediction)

KEYWORDS: Ocean Surface Gravity Waves, Directional Wave Spectra, Surf Zone, Wave Shoaling, Beach

TRANSIENT LOCALIZATION IN SHALLOW WATER ENVIRONMENTS

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In this work, the robustness of a simple, Bartlett-type processor based on matching broadband signal autocorrelation functions is investigated. Measures of robustness to be examined include the size of the localization footprint on the ambiguity surface and the peak-to-sidelobe levels in the presence of environmental mismatch and noise. A full-wave PE model is used to produce broadband replicas. Both model-generated synthetic signals, which provide baseline results, and measured pulses in a shallow water environment are analyzed.

This work suggests that environmental mismatch has a more significant effect on the localization performance than noise. It also suggests that, as long as the noise level is not higher than the signal level, the localization performance will not be significantly affected. This is to be expected, since for white noise the majority of the influence on the autocorrelation function occurs at zero lag which has been removed in the localization algorithms. It is also shown that the autocorrelation matching in the time-domain is generally more useful for smaller bandwidths at low frequencies, which has been observed in previous work, whereas the autocorrelation matching in the frequency-domain is better suited for larger bandwidths and higher frequencies.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Autocorrelation Matching, Transient Localization, Shallow Water

A WIND-FORCED MODELING STUDY OF THE CANARY CURRENT SYSTEM FROM 300 N TO 42.50 N

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A high-resolution, multi-level, primitive equation ocean model is used to investigate the roles of wind forcing and irregular coastline geometry in the generation of currents, eddies, jets and filaments in the Canary Current System (CCS) from 300 N to 42.50 N. To study the generation, evolution, and sustainment of the currents, eddies, jets and filaments in the CCS, the model is forced from rest using seasonal climatological winds and a realistic coastline. Results of the experiment show that wind forcing alone is capable of generating surface currents, undercurrents, meanders, eddies, and filaments. Preferred eddy generation locations, enhanced growth of meanders, eddies, and filaments are seen. The features produced by the model are consistent with available observations of the CCS.

DoD KEY TECHNOLOGY AREAS: Battlespace Environment, Environmental Quality, Modeling and Simulation

KEYWORDS: Primitive Equation Model, Canary Current System, Currents, Meanders, Eddies and Filaments

ANALYSIS OF EDDY RESOLVING MODEL OF THE CALIFORNIA CURRENT SYSTEM

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A high-resolution, multi-level, primitive equation ocean model is used to investigate the combined role of seasonal wind forcing, thermohaline gradients, and coastline irregularities on the formation of currents, meanders, eddies, and filaments in the California Current System from 22.5∞ N to 47.5∞ N. An investigation of the dynamical reasons for the generation and growth of meanders and eddies is conducted along with a sensitivity study to investigate the formation of the Davidson Current.

Model results are consistent with the generation of eddies from instabilities of the equatorward current and poleward undercurrent via barotropic and baroclinic instability processes. The meandering equatorward jet south of Cape Blanco is shown to be a continuous feature, which divides coastally-influenced water from water of offshore origin. The area off southern Baja is shown to be a highly dynamic environment for meanders, filaments, and eddies, while the area off Point Eugenia is shown to be a persistent cyclonic eddy generation region. Both the Southern California Countercurrent rounding Point Conception and the shoaling of the poleward undercurrent are shown to play important roles in generating the Davidson Current in the fall.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Primitive Equation Model, California Current System, Currents, Meanders, Eddies, Filaments

COMPARISON OF ADVANCED ARCTIC OCEAN MODEL SEA ICE FIELDS TO SATELLITE DERIVED MEASUREMENTS

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Numerical models have proven integral to the study of climate dynamics. Sea ice models are critical to the improvement of general circulation models used to study the global climate. The object of this study is to evaluate a high-resolution ice-ocean coupled model by comparing it to derived measurements from Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imager (SSM/I) satellite observations. Utilized for this study was the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) Sea Ice Concentration Data Set from the National Snow and Ice Data Center. Using animations of side-by-side presentations, variability comparisons and anomaly values of the similarities and differences between the model and the satellite were noted. The model shows a true representation of the seasonal cycle of ice concentration variation, with natural growth, advection, decay. Model performance is weakest in the East Siberian and Laptev Seas where excessive ice is developed. A 30-day lag in the freezing and melting of ice in Hudson Bay was noted in the model. The use of monthly mean Levitus temperatures adversely affects model performance evidenced by a tendency to grow and retain excess ice in the marginal seas of the Arctic Ocean.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Space Vehicles

KEYWORDS: Numerical Models, Climate Dynamics, Sea Ice General Circulation Model, SMMR (Scanning Multichannel Microwave Radiometer), SSM/I (Special Sensor Microwave/Imager), Satellite, NASA National Aeronautics and Space Administration), Goddard Space Flight Center, National Snow and Ice Data Center, Ice Concentration, East Siberian and Laptev Seas, Hudson Bay, Arctic Ocean

VERTICAL AND HORIZONTAL LENGTH SCALES OF SUSPENDED SEDIMENT IN THE NEARSHORE

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Suspended sediment measurements acquired using acoustic and optical sensors are analyzed to determine the vertical and horizontal coherence length scales in the nearshore zone across a barred beach during the SandyDuck experiment.

Suspended sediments over the vertical, from the seafloor to approximately 65 cm above the bed, are inferred from acoustical backscatter of a 1.3 Mhz signal at discrete 1.7 cm bins. The height of the bedload layer ranged from 1.7 – 3.4 cm above the bed floor for all stations investigated, which is twice the height of the theoretical wave boundary layer. The vertical coherence length was found to be an order of magnitude greater than the wave boundary layer and had a weak dependence with wave height, depth of water and orbital excursion (linear correlation coefficient of 0.6 statistically significant at 95% confidence).

The cross-shore horizontal coherence length scale of suspended sediment was determined using a two meter lagged array of six optical backscatter sensors at an elevation of approximately 18 cm above the bed. The horizontal coherence length scale was approximately 0.8 times the rms wave orbital excursion length for all cross shore stations. Both the vertical and horizontal coherence length scales are longest for infragravity waves and decrease with increasing frequency.

DoD KEY TECHNOLOGY AREA: Other (Littoral)

KEYWORDS: Suspended Sediment Length Scales, Suspended Sediment, Nearshore

LOW FREQUENCY ACTIVE SONAR (GENERIC UK) PERFORMANCE ASSESSMENT IN THE OPERATIONALLY SIGNIFICANT AREA OF THE NORTHWEST APPROACHES TO THE UNITED KINGDOM

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The goal of this research was to make a performance assessment for a generic UK Low Frequency Active Sonar (LFAS) operating in the northwest approaches to the UK. Five diverse and operationally significant sound speed and geoacoustic transects of the region in winter and summer were considered. The intention was to use an operational, ray theory based, acoustic propagation loss model for the performance assessment at 400 Hz and 800 Hz for various source/target depths. Prior to the assessment the ray model was compared with a finite element primitive equation transmission loss model (RAM) to, firstly, validate the propagation loss algorithms, and, secondly, to make any required corrections to the ray model propagation loss output as a result of variable geoacoustic conditions. Results show that the ray model compares favorably with RAM and only minor corrections were required. RAM was also used to evaluate the effect of the South East Icelandic Front in summer on acoustic propagation at the frequencies of interest. Results demonstrate that, depending upon source/receiver dispositions, the inclusion of range dependent sound speed profiles and geoacoustic parameters are a necessity. LFAS performance results demonstrate that the system is able to achieve good results with lower frequencies performing better than high frequencies. However, high reverberation levels are a severe limiting factor. Investigation into advanced signal processing techniques suggest that the utilization of inverse beamforming techniques has the potential to improve detection opportunities by suppressing reverberation.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors, Modeling and Simulation

KEYWORDS: Oceanography, Propagation Loss, Low Frequency Active Sonar, Performance Assessment, Northeast Atlantic, Inverse Beamforming

AIR-SEA INTERACTIONS AND WATER MASS STRUCTURE OF THE EAST CHINA SEA AND YELLOW SEA

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The climatological water mass features, the seasonal variabilities of the thermohaline structure, and the linkage between fluxes (momentum, heat, and moisture) of the East China and Yellow Seas have been investigated. The long-term mean surface heat balance corresponds to a heat gain of 15 W m^{-2} in the Yellow Sea shelf (YS), a heat loss of around 30 W m^{-2} in the East China Sea shelf (ECS) and Cheju bifurcation zone (CB), and around 65 W m^{-2} in the Taiwan Warm Current region (TWC) and Kuroshio Current region (KC). The surface fresh water balance, i.e., evaporation minus precipitation, ranges from -1.8 to -4.0 cm/month for the five subareas. The four seasons for the study area are divided based on the relative heat storage, which do not follow the usual atmospheric seasons. The entire water column of the ECS, YS, and CB undergoes a seasonal thermal cycle with maximum values of temperature during summer and maximum mixed layer depths during winter. Only the surface waters of TWC and KC exhibit a seasonal thermal cycle. Two patterns exist in the surface salinity and Yangtze River run-off, out of phase in the East China Sea and in phase in the Yellow Sea.

DoD KEY TECHNOLOGY AREA: Other (Physical Oceanography)

KEYWORDS: Water Mass Features, Thermohaline Structure, Seasonal Cycle

THE SOUTH CHINA SEA THERMOHALINE STRUCTURE AND CIRCULATION

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The South China Sea (SCS), the largest marginal sea in the West Pacific Ocean, is separated from adjacent oceans by a chain of islands. The deepest water is confined to a bowel-type trench, and the maximum depth is approximately 5,000 m. Most of the existing studies on the seasonal and interannual variability have been based only on surface temperature data. However a primary need is an understanding of the three-dimensional thermohaline circulation. The minimum curvature with spline method was used to establish a three-dimensional monthly-varying gridded data from the Navy's Master Oceanographic Observation Data Set (approximate 189,000 profiles), covering the area of 5°N - 25°N and 105°E - 125°E and from the surface to 400 m depth. For temperature, profiles were binned into 204 monthly data sets from 1968 to 1984 (17 years). Because of the paucity of salinity data, salinity profiles were binned into 12 climatological monthly data sets, and the monthly climatological mean was computed. After the gridded data set had been established, both composite analysis and the Empirical Orthogonal Function (EOF) analysis were used to identify the major thermohaline features. The first EOF mode accounts for 26.7% of the variance and represents the seasonal variation. The second EOF mode accounts for 17.7% of the variance and represents the interannual SCS warming/cooling phases. Furthermore, the P-vector method was used to invert three-dimensional velocity fields from the analyzed temperature and salinity

data. Important dynamical processes, including the Kuroshio intrusion, the western boundary current (counter-current), the cross basin current (under counter-current), the mesoscale eddies, and the basin gyre are identified.

DoD KEY TECHNOLOGY AREA: Other (Physical Oceanography)

KEYWORDS: Water Mass, Thermohaline Structure, Seasonal Variation, Circulation

ESTIMATING THE ACOUSTIC MODAL ARRIVALS USING SIGNALS TRANSMITTED FROM TWO SOUND SOURCES TO A VERTICAL LINE HYDROPHONE ARRAY IN THE 1996 SHELFBREAK PRIMER EXPERIMENT

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During the 1996 multi-institutional Shelfbreak PRIMER experiment, low frequency sound sources were moored on the continental slope south of Cape Cod. These sources transmitted phase encoded tomography signals which were monitored by vertical-line hydrophone arrays moored on the continental shelf. The measured signals were processed for the acoustic modal arrivals and their variability in time. The processing entailed pulse compression, coherent averaging, local sound-speed profile updates and an application of the Chiu-Miller-Lynch model-based modal beamforming technique. In this thesis, the signal processing procedure is discussed and the modal arrival estimates are examined. The model-based estimates are found to be of high quality, with all propagating modes individually resolved. This unambiguous separation of the high modes cannot be achieved using simple least-squares techniques because of under sampling. The temporal variability of the modal amplitudes and travel times are found to be related to ocean processes that are unique to the shelf-slope littoral environment.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Acoustics, Array, Mode, Processing

STRUCTURE AND VARIABILITY OF THE MESOSCALE CIRCULATION IN THE CARIBBEAN SEA AS DEDUCED FROM SATELLITE ALTIMETRY

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Four years of Topex/Poseidon (TIP) and European Remote Sensing Satellite (ERS) altimetry data in the Caribbean Sea are used to describe the structure and variability of the mesoscale circulation in this area. These results are compared with satellite-derived sea surface temperature (SST) and drifter trajectories for the same period of time. Contour maps of sea surface height anomalies made for each 10-day period (TIP data) reveal the formation and evolution of anticyclonic and cyclonic mesoscale features in the central part of the Caribbean Sea during the entire period studied. These features move westward at average speeds between 10 and 15 cmls, growing in amplitude up to 25 cm. Also, a quasi-permanent gyre is detected in the Golfo de los Mosquitos (coast of Panama and Colombia). The sense of rotation of this gyre is shown to be modulated seasonally. Enhanced relative clockwise and counterclockwise rotation are observed during the rainy season (June-October) and the dry/windy season (January-April), respectively. No strong mesoscale anomalies are detected in the eastern part of the Caribbean Sea where they are expected. A seasonal cycle is found in the sea level anomaly (SLA) derived from TIP and ERS-1 data due to steric effects. Upwelling is observed near the coast of Venezuela during the dry season. A

comparison of SLA with SST is made and good correlation is observed at some locations. Drifter trajectories contemporaneous with SLA data agree well with the sense of rotation of strong features, but the drifter speeds are twice the absolute geostrophic currents calculated from SLA.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Sensors

KEYWORDS: Caribbean Sea, Topex/Poseidon (TIP), ERS-l, Mesoscale Variability, Eddies, Sea Level Anomal (SLA), Satellite Altimetry

A P-VECTOR APPROACH TO ABSOLUTE GEOSTROPHIC CURRENTS IN THE ADRIATIC SEA

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With the recent conflict in Bosnia-Herzegovina being in the world news front, the Adriatic Sea has become an important strategic operating area for the North Atlantic Treaty Organization (NATO) and for the U.S. Navy. The NATO Undersea Research Centre located in La Spezia, Italy, carried out the Otranto Gap (OGAP) project in 1994 and 1995 to assess the oceanography and bottom geology of the Southern Adriatic. As part of this project, the OGEX1 cruise was conducted between 19 and 24 May 1995 with focus in the Otranto Strait, through which the Adriatic is connected to the rest of the Mediterranean basin and on the Albanian shelf. In this thesis the water masses present in the southern Adriatic are studied and the P-vector method is used to estimate the absolute geostrophic circulation, based on the hydrographic data (CTD, XCTD, and XBT) collected during the OGEX1 cruise. The P-vector results are interpreted and compared with other oceanographic data sets acquired during the OGAP project, namely current meter and ADCP data, drifter tracks, and thermal satellite images. The absolute geostrophic velocity at 40 m, derived by the P-vector method, shows rather well the expected cyclonic circulation in the Southern Adriatic north of 41°N. In contrast, the results in the Otranto Strait area need to be interpreted with caution. Current meter data show that this area is very ageostrophic. A comparison between geostrophic and directly measured vertical velocity shears indicates a large departure from geostrophy in this area. The wind is shown to be a main factor forcing the circulation in the Adriatic, either directly or through changes in sea level.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Adriatric Sea, P-Vector Method, OGEX1, Current Meters, Drifters, Floats, ADCP

SPECTRAL ENERGY BALANCE OF WAVES IN THE SURF ZONE

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The spectral energy balance of waves in the surf zone is examined with extensive measurements from the Duck94 experiment. Cross-shore energy flux gradients are estimated from spectra observed with closely spaced pressure sensors. Nonlinear energy exchanges between different wave components in the spectrum are estimated from observed bispectra based on Boussinesq theory for near-resonant triad interactions. Dissipation of wave energy in the poorly understood breaking process is inferred as the residual term in the spectral energy balance.

Analysis of the spectral energy balance shows that large decreases in energy flux observed at the dominant wave frequencies as waves break over a sand bar are closely balanced by nonlinear energy transfers to higher frequencies. That is, the decay of the spectral peak within the surf zone is a result of nonlinear energy transfers rather than direct dissipation. At

higher frequencies, observed energy flux gradients are small and do not balance the nonlinear transfers of energy to high frequency components of the spectrum. This analysis suggests that the spectrum is saturated at high frequencies, and thus, the energy that cascades through nonlinear interactions to higher frequencies is dissipated in the high-frequency tail of the spectrum.

DoD KEY TECHNOLOGY AREA: Other (Physical Oceanography)

KEYWORDS: Dissipation, Energy Balance, Boussinesq Equations, Ocean Surface Gravity Waves, Nonlinear Interactions, Shoaling, Beach, Energy Flux

MODEL ANALYSIS OF ENERGY SPREADING LOSS OFF THE CAROLINA COAST FOR TACTICAL ACTIVE SONARS

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Energy spreading loss (ESL) is the reduction of the transmitted pulse energy level by spreading of the pulse in time due to multipath propagation. This energy spreading will reduce the effectiveness of mid-frequency tactical sonars. The U.S. Navy training areas of Long Bay and Onslow Bay off the Carolina Coast were chosen for the study of ESL to provide contrasts in many of the geoacoustic properties that can change ESL. Inputs were varied by source depth, receiver depth, sound speed profile (SSP), bathymetry, and geoacoustic properties. The computer model FEPE_SYN calculated the ocean transfer function (OTF) for the modeled environment in the frequency domain. The time domain output pulse was calculated using the OTF, an input pulse, and an inverse discrete Fourier transform. Using the same energy as the output pulse, a compressed pulse was created with the same shape as the input pulse. ESL was determined by comparing the peak level of the output pulse to the peak level of the compressed pulse. A mismatch loss (MML) was calculated by comparing the maximum values from the correlation of the input pulse with the output pulse and compressed pulse.

The ESL of the output pulse was dependent on several factors. Absorptive (silt/clay) sediment sea beds had average ESL values 3 dB less than that of compacted sand. The compacted sand bottom was also compared to an even more reflective sediment, a limestone sediment layer. ESL values were higher by an additional 3 dB for the limestone bottom. Minimum ESL levels were found when the source and target were at the same depth. Changing source and target depths (e.g., cross layer) could increase ESL levels up to 8 dB from the minimum ESL level. The impact of using a range-dependent SSP vice constant SSP was inconclusive in that ESL values could be larger or smaller by 3 dB compared to range-independent runs. Similar inconclusive results were obtained when actual bottom depths were employed vice a flat-bottom run. As found by Tanaka (1996), ESL was observed to rapidly increase in the first 1000 m and thereafter fluctuate around a mean value. This initial critical range is evidently site dependent but appears to be confined between 300 to 1000 m range.

DoD KEY TECHNOLOGY AREA: Battlespace Environments, Sensors

KEYWORDS: Acoustics, Energy Spreading Loss, ESL, Underwater System, FEPE, FEPE_SYN, Active Sonar, Hamilton Geoacoustic Model, Transmission Loss, Mismatch Loss, MML, Time Domain Analysis

IDENTIFICATION OF ACOUSTICALLY ACTIVE ARCTIC PRESSURE RIDGES THROUGH THE USE OF RADARSAT GEOPHYSICAL PROCESSOR SYSTEM (RGPS) SEA ICE PRODUCTS

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The identification of acoustically active pressure ridges in the Arctic Ocean represents an important step in the development of a physics-based, operational Polar ambient noise model. One method to accomplish this goal is through the use of satellite-based remote sensors, specifically synthetic aperture radar (SAR).

A proof-of-concept study was conducted that determined that the RADARSAT Geophysical Processor System (RGPS), currently being developed at NASA JPL, Pasadena, CA, produces SAR-derived sea ice products capable of quantifying large-scale ice deformation that may produce significant levels of low frequency ambient noise. This research also identifies the meteorological forcing that causes the sequence of divergent and convergent events in the ice cover, which results in the creation of open water leads and subsequent generation of noisy pressure ridges. Offshore followed by onshore winds near coasts and land-fast ice and atmospheric lows/troughs followed by atmospheric highs/ridges or velocity shear in straight isobaric flow result in significant pressure ridge formation.

The RGPS ridging algorithm shows that more ridges exist in RGPS cells exhibiting large cell area changes than in those with small area changes, assuming relatively constant sail heights in all cells.

The feasibility of using ice divergence fields generated by Fleet Numerical Meteorology and Oceanography Center's (FNMOC's) Polar Ice Prediction System (PIPS) was evaluated. NIPS modeled ice divergence patterns reasonably well, although divergence values in the high Arctic ice cover were underestimated.

DoD KEY TECHNOLOGY AREA: Other (Remote Sensing, Arctic Ocean)

KEYWORDS: Polar Oceanography, Pressure Ridges, Open Water Leads, Ice Deformation, Synthetic Aperture Radar, RADARSAT, Geophysical Processor System, Polar Ice Prediction System, Low Frequency Ambient Noise, Arctic Submarine Operations, Remote Sensing

THE ROLE OF SALINITY IN EQUATORIAL MIXED LAYERS

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The purpose of this study was to understand the role of surface salinity flux in changing heat exchange between the ocean and the atmosphere by means of its effect on mixed layer dynamics. This was accomplished by a series of thirty-day mixed layer experiments using the one-dimensional Naval Postgraduate School (NPS) mixed layer model. Results from the NIPS mixed layer model, forced with both idealized and in situ data from the western equatorial Pacific Ocean, demonstrated that salinity can play a significant role in potentially changing the surface heat flux, with its effect on the mixed layer depth and mixed layer temperature. Precipitation stabilized the mixed layer by creating a barrier layer, which slowed entrainment. The net accumulation of rain was found to be an important source of buoyancy that reduces entrainment by subsequent wind mixing events.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Oceanic Mixed Layer, Salinity, Ocean Models

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